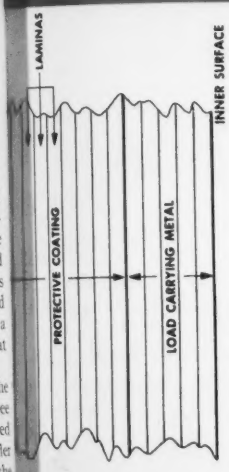
SCIENCE

AERO/SPACE ENGINEERING

VIEW OF CURRENT AND FUTURE TRENDS IN AIRCRAFT • MISSILES • ROCKETS • SATELLITES • SPACECRAFT



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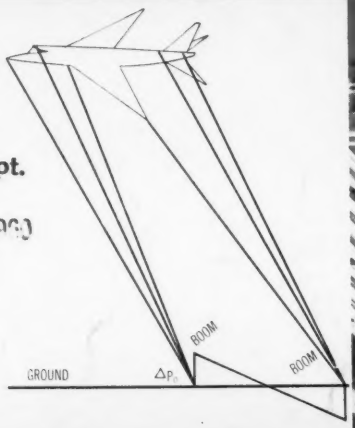

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- Heat
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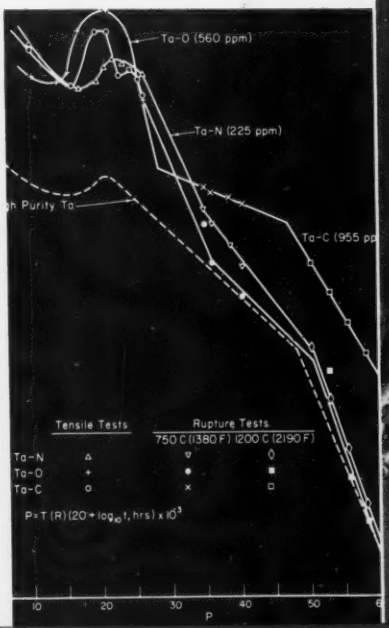
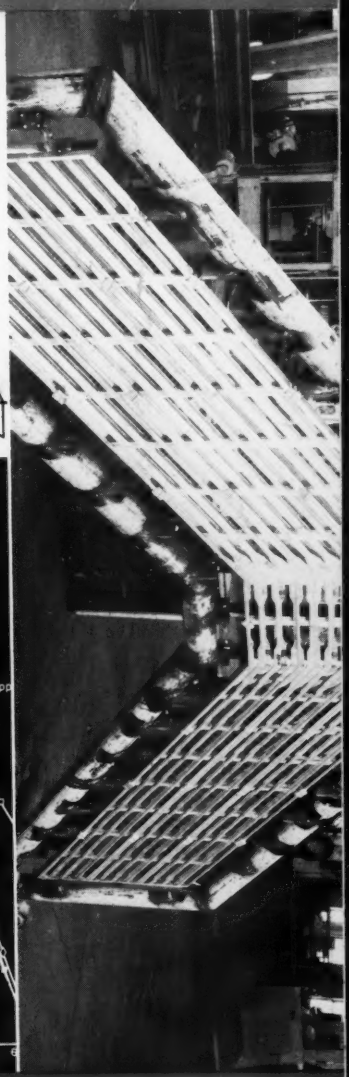
- Materials
- Editorial—Where do we go from here . . . ?





JULY / 1960

Minuteman

...Another major USAF weapon system in development

Minuteman, a three-stage solid propellant intercontinental missile, is moving through its early development and test programs on or ahead of the time schedule originally set for it. This advanced ICBM, the fourth in a family of four Air Force ballistic missiles, is designed to be fired automatically from underground silos or mobile launchers. Minuteman will be constantly at "ready" giving America an almost instantaneous retaliatory capability for defense • The Minuteman concept developed early in 1957 when Space Technology Laboratories conducted a study of the characteristics of second-generation missiles to satisfy the requirements of the Air Force Ballistic Missile Division. STL provides over-all systems engineering and technical direction for Minuteman as it has for the Atlas, Titan, and Thor programs. The application of compatible components, systems, and experience developed through the years is bringing Minuteman closer to the threshold of operational capability • Among the industrial organizations developing Minuteman are such major contractors as: Boeing Airplane Company for assembly and test; Thiokol Chemical Corp., Aerojet General Corp., and Hercules Powder Company for engines; Autonetics, a Divisionof North American Aviation for guidance; and Avco Corp. for re-entry vehicle.

To assure continued growth in these and related space programs, STL is already projecting state-of-the-art advances five and ten years ahead. Outstanding scientists and engineers with unusual capabilities in propulsion, electronics, thermodynamics, aerodynamics, structures, astrophysics, computer technology, and other related fields and disciplines are invited to investigate positions at STL. Please send resumes to:

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AERO/SPACE ENGINEERING

VOLUME 19 / NUMBER 7 July 1960

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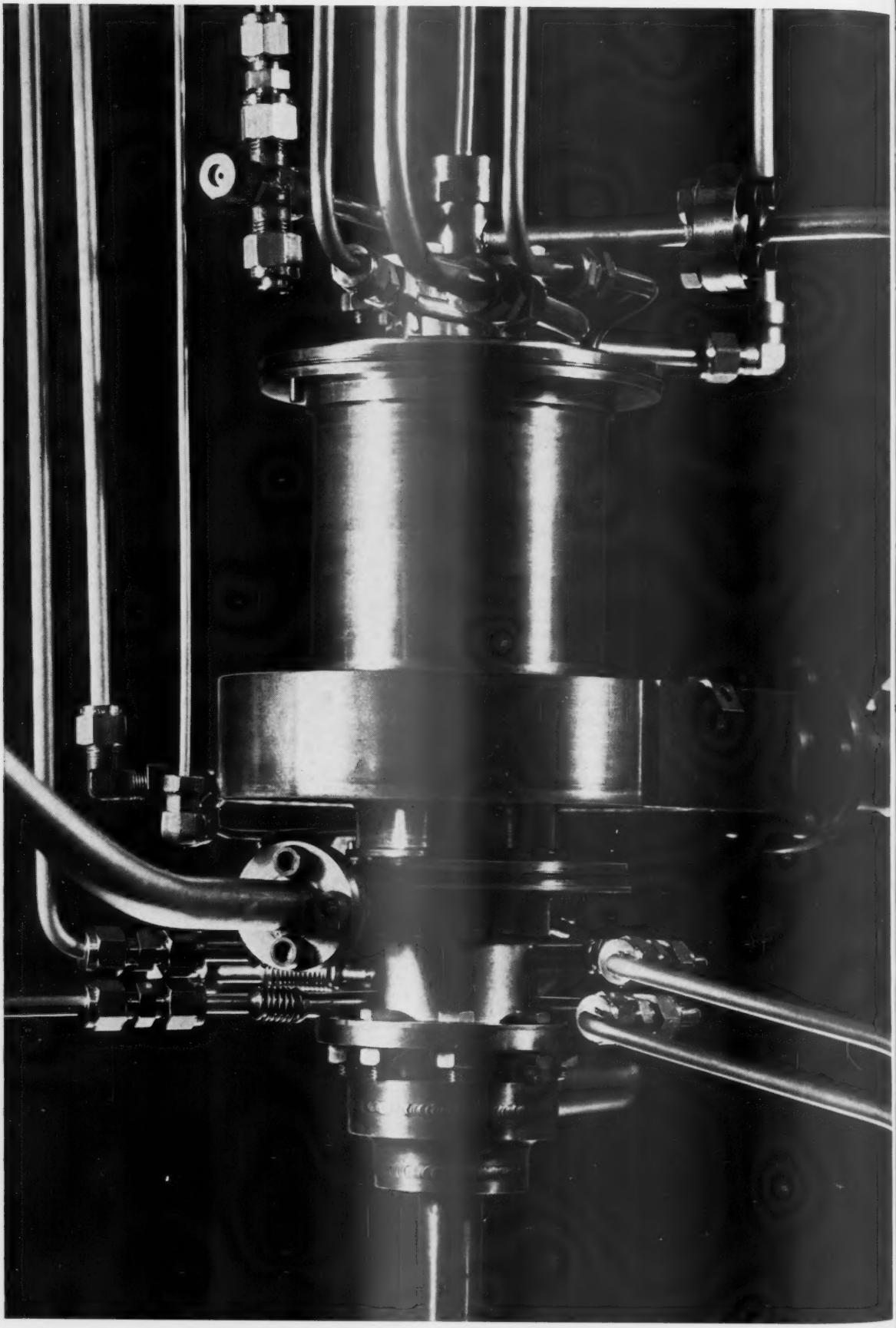

IAS News

. . . a record of people and events of interest to Institute Members

1960 Octave Chanute Award Presented to FAA Flight Test Engineer

Joseph J. Tymczyszyn Cited for Contribution to Jet Transport Certification Program

THE OCTAVE CHANUTE AWARD of the IAS, given annually for a "notable contribution made by a pilot to the aeronautical sciences," has been presented to Joseph J. Tymczyszyn, Flight Test Engineer and Pilot for the Federal Aviation Agency. The award, which cited Mr. Tymczyszyn "for notable contribution in the inauguration of the jet age through outstanding flight test activity in the certification programs for the new jet transports," was made at the Institute's National Summer Meeting in June.

A test pilot for the FAA (and CAA) for 12 years, Mr. Tymczyszyn has for the past 2 years been assigned exclusively to the testing of jet transports—beginning with the first American jet transport, the Boeing 707-120, and most recently the Douglas DC-8 series. He has spent many hours of his own time conducting flight tests for and working out solutions to unprecedented and unanticipated problems.

Joseph J. Tymczyszyn
1960 Octave Chanute Award Winner

Pilot and Engineer

Born August 12, 1918, in Wilkes-Barre, Pa., Mr. Tymczyszyn attended the University of Denver, completing 3 years of aeronautical engineering while working at flying school to obtain training for a commercial flying license. He also completed acrobatic, cross-country, apprentice-instructor, and instructor training courses under the Civilian Pilot Training program. He served as a flight instructor in CPT primary and acrobatic courses prior to entering the Air Force in 1942, where he served as a civilian advanced twin-engine (AT-9) flight instructor until completing all Air Force training and instructor courses and receiving his commission with a Pilot rating. He served during World War II, first as an instructor and later as flight-test engineering and maintenance officer and pilot, flight testing various combat aircraft.

Returning to civilian life, Mr. Tymczyszyn entered the University of Washington to complete requirements for his B.S. in Aeronautical Engineering. During this 2-year period he worked at the University's 8 ft. × 12 ft., 250-m.p.h. wind tunnel on aerodynamic tests of advanced design aircraft.

Joining the Civil Aeronautics Administration upon graduation (1948), he served as a project test pilot for CAA Region V for 4 years before being transferred to the Los Angeles office. He has served as test pilot for well over 40 projects—among them all or major portions of the jet transports previously named, the Lockheed 1649 Jetstream, Lockheed's Super Constellation series, Douglas DC-7B, 7C, and 6B series, and Convair 340-440 turboprop modifications.

Jet Certification

The coming of the jet age in civil aviation produced a certification problem with the need for a new set of performance regulations and the creation of difficulties not before covered by regulations. Mr. Tymczyszyn's efforts have contributed greatly to the success of the certification programs for the new jet transports.

The nature of his position requires, in addition to quantitative testing, a qualitative evaluation of an airplane's eligibility for civil certification. With difficult timing as an important consideration, Mr. Tymczyszyn's professional approach and independent thinking have qualified him for his assignments. He has, moreover, recognized the importance of conveying sound information to personnel concerned with operating the aircraft.

Mr. Tymczyszyn is an Associate Fellow of the Society of Experimental Test Pilots, and was the 1958 recipient of their Iven C. Kincheloe Award for Outstanding Pilot Achievement. Holder of an airline transport rating, as well as commercial, instrument, instructor, and seaplane ratings, he has logged over 7,300 pilot hours, 2,800 of which are test flight hours.

The Award

The Chanute Award, consisting of a certificate and honorarium, was established shortly after the founding of the IAS. It honors the memory of a United States pioneer aeronautical investigator who died in 1910. Last year's winner was John P. Reeder, Chief of the Flight Operations Branch, Flight Research Division, NASA Langley Research Center. Mr. Reeder was cited "for extended and significant contributions to aircraft flight research, with particular reference to the safe operation of helicopters during the landing approach under adverse weather conditions."

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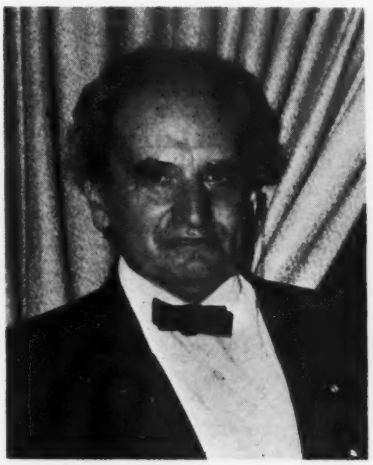
"GOOD WILL" is the disposition of the pleased customer to return to the place where he has been well treated.
– U.S. Supreme Court

Second ICAS Congress Scheduled for September in Zurich

Societies of 24 Nations to Share Technical Data, Other Activities

Additional plans for the Second International Congress of the International Council of the Aeronautical Sciences (ICAS) have been completed by the Executive and Arrangements Committees. The technical program for the Congress was announced in the Green Sheet of AERO/SPACE ENGINEERING's June issue. The meeting, sponsored by scientific societies of 24 nations, will be held September 12–16, 1960, in Zurich, Switzerland.

The technical program, to open with the Daniel and Florence Guggenheim Memorial Lecture, is made up of sessions on Hypersonic Flow; Boundary Layer, Transonic and Supersonic Flow; Fatigue of Materials; Aerothermochemistry; Nonstationary Transonic Flow; Air Transport; Magneto Fluid Dynamics; Structures and Fatigue; Flows With Chemical Reactions; Aeroelasticity; Entry From Space; Aerospace Medicine; and Space Flight. All technical sessions will be held in Grösser Hörsaal für Experimentalphysik of the Eidgenössische Technische Hochschule (ETH). Interpreting equipment will be provided at all sessions, with papers presented in the three languages of the Congress—English, French, and German. Plans call for publication of papers and discussions in the form of proceedings, as well as having preprints of individual papers available at the meeting.



Theodore von Kármán

Dr. Theodore von Kármán, President of ICAS, will preside at the meeting. The program and arrangements for the Congress have been organized by committees chairmanned by Maurice Roy, Director of Office National d'Etudes et de Recherches Aéronautiques, and Dr. Manfred Rauscher, Professor, ETH, and President of the Swiss Aeronautical Society. The Guggenheim Lecture, "The Role of Entropy in the Aerospace Sciences," will be delivered by Jakob Ackeret, Professor, Institut für Aerodynamik, ETH.

Arrangements are also being made for a more social side of the Congress. Wives of some of the members of the Swiss Aeronautical Society are planning activities for the ladies. On the evening of Friday, September 16, a banquet will be held in the Convention Hall in Zurich. In addition, since no sessions have been scheduled for Wednesday afternoon, September 14, the Committee has chartered a boat for a 3-hour sail on Lake Zurich. Tickets for the banquet and boat ride will be available to delegates at the meeting.

The Swiss Aeronautical Society, as hosts for the Congress, are providing the facilities at ETH and the necessary staff to man the meeting. Additional financial support for ICAS is derived from the Daniel and Florence Guggenheim Memorial Fund of the IAS. Members wishing to attend may apply directly to the ICAS Secretariat, attention of Robert R. Dexter at IAS headquarters in New York.

Jakob Ackeret

Manfred Rauscher

Maurice Roy

Igor Sikorsky, IAS Founder Member and Honorary Fellow, Delivers Second Gardner Lecture

Basing his discussion on highlights of his aviation career which now spans 51 years, Igor Sikorsky, IAS Honorary Fellow and Founder Member, delivered the Second Lester D. Gardner Lecture in the Kresge Auditorium of Massachusetts Institute of Technology on April 14.

The lectures, initiated last year by Grover Loening, are made possible by a bequest of the late Major Gardner to sponsor annual lectures on the history of aeronautics. Lester Gardner, an 1898 graduate of MIT, was the Founder of the IAS and a dedicated aviation enthusiast until his death in 1956.

Mr. Sikorsky recalled that "in 1909 aeronautics was neither an industry nor even a science; it was an art and . . . a passion. Money earned by demonstration flights and winning of prizes was not considered an objective in itself. It was regarded only as a means of pushing forward the miraculous art of flying."

Turning from the past to the future, Mr. Sikorsky visualized use of the crane helicopter with airliners to bring unprecedented speed and convenience to air passengers. Citing several applications in which these units may work together to accomplish a variety of missions, Mr. Sikorsky suggested that one such mission may be carrying comfortably-outfitted pods that can be loaded with passengers and their luggage in the heart of a city and delivered by a crane helicopter to the end of a runway to a waiting long-distance jet airliner into which the passengers could be transferred comfortably and quickly. The procedure would be reversed upon arrival at destination. Another possibility suggested by Mr. Sikorsky was the launch and lowering of a 24-passenger jet liner by crane helicopters, permitting trips by air directly from the heart of one city to the heart of another.

Mr. Sikorsky built and attempted to fly helicopters in his native Russia as early as 1909. Temporarily abandoning this field, he turned to fixed-wing aircraft. He came to the United States in 1919, and four years later established the Sikorsky Aero Engineering Corporation. Here he worked with large airplanes, leading to the development of the flying boats which made possible commercial flying across both oceans. In 1939, he returned to helicopter designs and built and flew the first successful helicopter in the Western hemisphere.

In 1929, Mr. Sikorsky's company became a division of United Aircraft Corp., with Mr. Sikorsky as Engineering Manager. Since his retirement in 1957 he has served as consultant on such advances as the use of turbine power and crane concept for helicopters.

Mr. Sikorsky holds the John Scott Medal awarded by the City of Philadelphia (1939), the Potts Medal of the Franklin Institute (1933), the Sylvanus Reed Award of the IAS (1943), the Guggenheim Medal (1951), and the Collier Trophy (1950). In addition, he received the James Watt International Medal in England (1955), and earlier this year was made a Chevalier of the French Legion of Honor. He is an Honorary Fellow of the Royal Aeronautical Society.

Igor Sikorsky

Sacramento 36th Section

The Sacramento Section of the Institute of the Aeronautical Sciences held its inaugural meeting on April 26. The dinner meeting was preceded by a social hour sponsored by Aerojet-General Corp.

IAS President Donald L. Putt welcomed the new section, the Institute's 36th, presenting Chairman Russell D. Archibald with an IAS charter. Following a brief business meeting for formal adoption of a constitution, George Stoner, Dynasoar Program Manager for Boeing Airplane Co., addressed the gathering. Mr. Stoner discussed "The Effect of Innovation on the Next Decade of the Space Age," presenting comments and theories on possible methods for advancing the state of the art.

This addition to the Institute's growing number of sections is composed of 80 engineers and scientists in the aerospace field, most of whom are former members of the San Francisco Section. Temporary officers, appointed by a steering committee in March to hold office until the June business meeting, were as follows: Russell D. Archibald, Chairman; E. P. Eales, Vice-Chairman; Roger D. Entz, Secretary; and Luther Lee, Jr., Treasurer.

Douglas Officer Retires; Management Personnel Reassigned

The recent retirement of Arthur E. Raymond, HFIAS, as Senior Vice-President—Engineering, Douglas Aircraft Co., after 35 years with the company, has effected a realignment in the company's engineering management. Edward F. Burton, FIAS, formerly Vice-President—Engineering, Transport Aircraft Systems, succeeds Mr. Raymond with the title of Vice-President—Engineering. Mr. Burton is assisted in technical matters by Elmer P. Wheaton, AFIAS, formerly Vice-President—Engineering, Missiles and Space Systems, and in administrative matters by R. L. Hoskinson, recently Director of Flight and Testing. In another change, Edward H. Heinemann, MIAS, Vice-President—Engineering, Combat Aircraft Systems, has been named Head of the company's European operation. Mr. Heinemann is a member of AERO/SPACE ENGINEERING'S Editorial Advisory Committee, Design, Structures, and Materials Panel.

Chanute Award Winner Joins Aviation Consultant Firm

Ernest A. Cutrell, 1946 winner of the Octave Chanute Award of the IAS, has joined the aviation consultant firm of R. Dixon Speas Associates. Mr. Cutrell, one of the nation's leading authorities on development of all-weather operations for transport aircraft, was cited "for outstanding achievement in flight testing and developing instrument landing equipment and techniques contributing to improved performance of instrument flying." Mr. Cutrell was previously associated with American Airlines, Eastern Air Lines, and the United States Air Force.

Air Safety Seminar

The Flight Safety Foundation, in cooperation with Aviation Crash Injury Research, will hold its 13th Annual International Air Safety Seminar November 14–18, 1960, in Phoenix, Ariz.

IAS Director S. Paul Johnston is a member of the Foundation's Board of Directors.

(*IAS News, Continued on page 48*)

Necrology

Bella C. Landauer

Bella C. Landauer (B), who in 1940 made her first gift to the Archives of the Institute of the Aeronautical Sciences, died at her home in New York City on April 23. She was 85 years old.

Over a period of years, Mrs. Landauer, a collector of printed matter, donated to the Institute a series of aeronautical music, trade cards, book plates, pictures, books, dime novels, medals, and medallions, making up one of the most comprehensive collections of aeronautical art in existence. She was made a Benefactor member of the IAS at the Honors Night Dinner in January, 1941.

Reginald E. Gillmor (AF)
April, 1960, Coral Gables, Fla.

Ivan Grzetic (A)
February, 1960, San Diego, Calif.

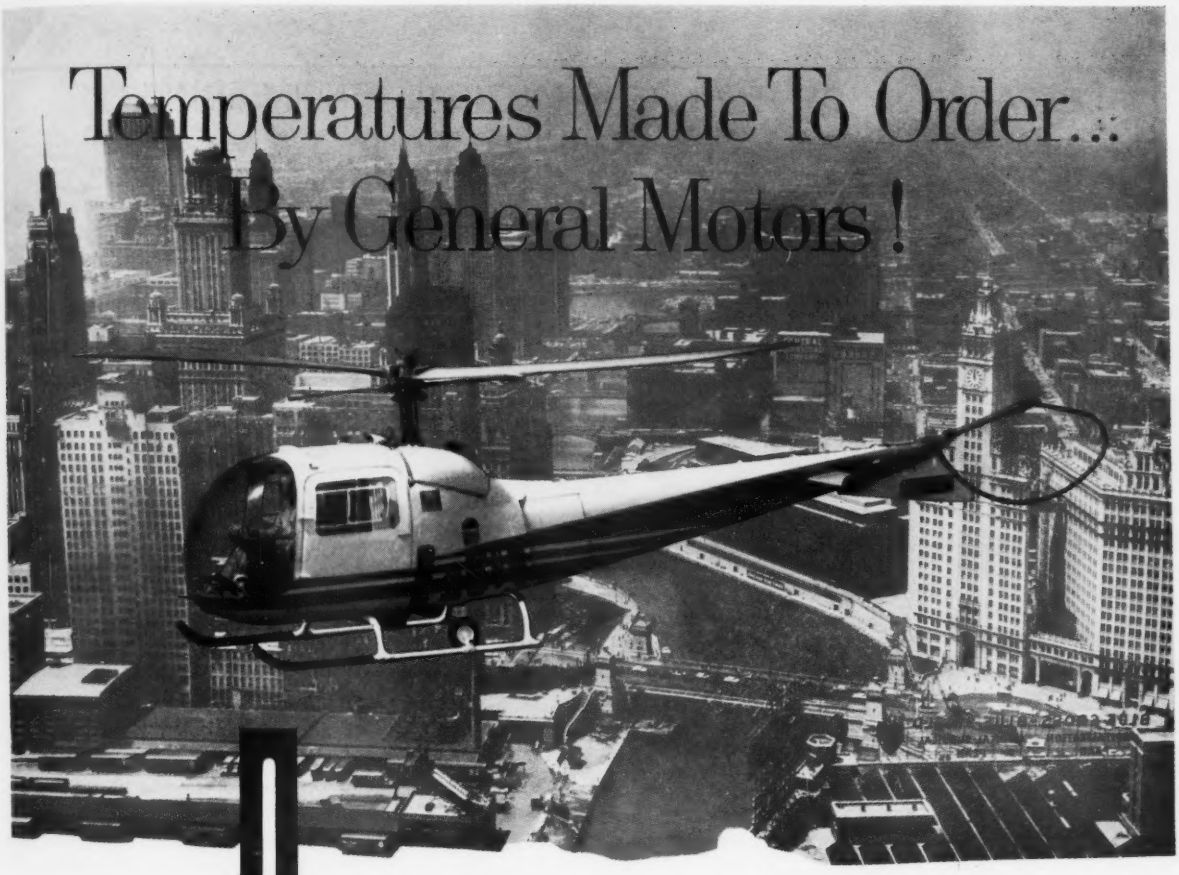
Harvey Hochman (A)
April 23, 1960, Stratford, Conn.

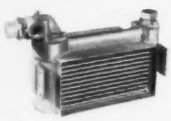
Herman T. Kraft (M)
April, 1960, Akron, Ohio.

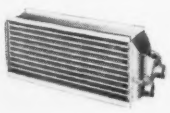
Harold F. Pitcairn (A)
April 23, 1960, Philadelphia, Pa.

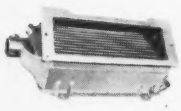
Leonard J. Waxer (A)
March, 1960, Dorchester, Mass.

Temperatures Made To Order...
By General Motors!









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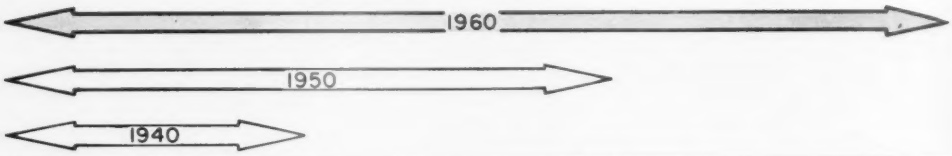
EXPANSION OF THE AERONAUTICAL ENGINEERING FIELD



	1940	1950	1960
Design	• Propeller Driven Airplane	• Subsonic Jet Airplane • Helicopter • Supersonic Missile	• VTOL • M=3 Airplane • Rocket Booster • Satellite • Reentry Vehicle
Theoretical Aerodynamics	• ideal fluid flow • low-speed airfoil & wing theory • incompressible viscous flow • turbulence	• aerothermodynamics • compressible flow • shock waves • transonic theory • supersonic airfoil & wing theory • compressible, viscous flow • boundary layer stability	• aerochemothermodynamics • hypersonic flow & airfoil theory • rarified gas flow • real gas effects • magnetohydrodynamics & plasmas • diffusion • ablation & evaporation • non-stationary aerodynamics
Applied Aerodynamics	• low-speed lift, drag, & moment • low-speed airplane performance • low-speed airplane stability & control • low-speed wind tunnel testing • linear constant parameter dynamics	• sub-trans-supersonic lift, drag, & moment • sub-trans-supersonic performance • sub-trans-supersonic stability & control • sub-trans-supersonic wind tunnel testing • helicopter performance • helicopter stability & control • non-linear dynamics	• hypersonic lift, drag, & moment • hypersonic performance, stability & control • hypersonic wind tunnel testing • variational techniques • dynamic performance • V/STOL performance • V/STOL stability & control • celestial mechanics • inertia coupling • time varying parameter dynamics • random processes
Propulsion	• internal combustion engines • propellers	• compressors • gas turbines • ram & pulse jets • liquid fueled rockets	• combustion processes • solid fueled rockets • electrical propulsion • nuclear propulsion • high temperature material
Structures	• strength of materials • trusses & beams	• elementary shell theory • fundamental elasticity • flutter	• advanced shell theory • stiffened shells • elasticity & plasticity • elastic & plastic stability • aeroelasticity • pressurized structures • solid state physics • fatigue • structures at high temperatures • sandwich construction
Guidance & Control	• aeronautical instruments	• servo theory • autopilots • stability augmenters • radio & radar guidance	• analog & digital computers • telemetry • stellar guidance • inertial guidance • adaptive controls

Courtesy Aeronautical Engineering Dept., Princeton University

EDITORIAL

Where do we go from here...?

In a recent meeting of the Advisory Council of the Department of Aeronautical Engineering of Princeton University, Dr. Courtland Perkins (now on temporary leave to the USAF) showed us a chart that had been made up for use in a presentation to President Goheen to point up the increasingly complex requirements levied against education in the Aerospace Age. The chart paralleled our own programing problem so closely that we thought it worth while to secure a copy. It is reproduced here with departmental permission.

More than 5 years ago it became evident that we were entering a period of very rapid technological expansion. We did not quite foresee the "explosion" that actually took place, but we were certain then that the situation was far from static. We recognized that methods that were used in the past to keep up with, and ahead of, the march of scientific events were no longer satisfactory. It had always been customary to call upon specialists in our several fields of interest for advice on programing and on editorial matters, but as time went on it became more and more difficult to keep informed on the professional interests of knowledgeable people, not to mention their location.

When we revised our Constitution in 1958, we adopted the device of "Aerospace Technology Panels" to help remedy this situation. In essence, these panels consist of selected groups of experts in particular fields who have agreed to act as advisers in their specialties to any IAS planning group. (See Editorial, March, 1960, issue of A/SE.) Panels have no collective planning or executive functions. It is not expected that all members of any panel will ever be required to meet as a group. Each panel chairman will, however, keep in touch with individual members (by phone, by carrier pigeon, or by bouncing signals off the moon) on questions that may be put to him by IAS program planners or by the IAS Technical Services Director Paul Burr. One of the new TSD's chief functions is to coordinate all panel activities.

During the past several months much work has been done in delineating individual panel responsibilities and in filling up the available "slots." In the August issue (along with the IAS ROSTER) the current membership of all panels will be listed. The panels replace the older Advisory Committees listed in past IAS publications.

Both in terminology and in composition, all panels are extremely flexible. The present titles and the membership were approved by the Council at the meeting on June 29 in Los Angeles. As the overall field of aerospace technology changes (as it undoubtedly will in the next 10 years, judging from the picture of the last two decades in the chart opposite), both the field of interest of the panels and the roster of "experts" who man them will undoubtedly change. New subjects may be added; old ones may drop out. This is a part of the IAS policy of continuous modification of technical programs to meet the expanding professional needs of IAS Members.

SPJ

Support Systems: Part I—Scope and Techniques

Beal M. Teague, AFIAS, *The Martin Company*

THE COST of a support system for one of today's ICBM's may represent as much as 50 to 80 per cent of the total cost of the weapon system. This seemingly high percentage is used to buy facilities, ground support equipment (GSE), and ground operational equipment (GOE).

Facilities: Installations such as buildings, substations, sewage disposal plants, and building heating and ventilating systems are typical facility items. Facilities are normally built in accordance with standard commercial practice and require no uncommon tolerances on power regulation, concrete strength, temperature, or other environmental conditions. Normally, facilities cannot be relocated in units or as a complete system.

GSE: Equipment needed prior to actual countdown and launch is termed GSE. Included in this category are trailers for missile delivery, cranes for positioning the missile on the launcher, and trucks used to carry and load propellants.

GOE: Equipment required in direct support of a missile during countdown and launch is termed GOE. Typical items in this category are checkout and launch control equipment, and launchers that support, guide, and rotate missiles for spin stabilization.

Facilities, GSE, and GOE, then, encompass the total ground system required to perform all functions in support of an airborne system. The size of a launch complex is generally determined by the quantity and arrangement of GOE and GSE, and by the personnel requirements for comfort and efficient operation of equipment and the complex.

One other commonly used term in the missile industry is ground support maintenance equipment (GSME). This equipment is used to maintain the airborne system while it is on the ground or to maintain the ground equipment. GSME is usually located at a maintenance or supply depot, although portable GSME may be used at the launch site. Typical GSME includes electronic checkout equipment to verify the integrity of "black-box" subsystems, mechanical equipment for flushing and cleaning engines, and lubrication kits for periodic maintenance of missile mechanical joints.

Mr. Teague, a past chairman of the Rocky Mountain Section of the IAS, is a Principal Engineer in the Base Systems Department at Martin-Denver, responsible for basing concepts of advanced design projects. He obtained his Aeronautical Engineering degree at the University of Alabama and joined Martin in Baltimore in 1940. The following 10 years he was active in structural and mechanical design of military airplane lifting surfaces and control systems. Mr. Teague became involved in ground systems in 1951 when he joined Van Zelm Associates of Baltimore as Project Engineer for aircraft arresting gears, catapults, and associated devices. In 1955 he rejoined Martin in time to become responsible for Titan mechanical system proposal and the ground support concept. He moved to Denver with the project in 1956 to set up and manage the ground support effort during the critical conceptual design engineering phase. Since January, 1958, he has been associated with new design activities for support systems.

Industry today is well aware of the cost of support systems. Consider, for example, the comparison between a meager support system for airplanes of World War II vintage and a complicated and expensive support system required for a present ICBM. The cost of a support system for an ICBM may be several times the cost of a single missile in the weapon system. Of course, airplanes and many missiles do not require a new set of equipment for each airborne vehicle, and the support system cost can be amortized over many units.

Although the aerospace engineer today appreciates the value and cost of support systems, he may not be familiar with their derivation and with provisioning procedures. Some of the current techniques are presented in the following paragraphs.

Derivation of Support Systems

Industry today rarely identifies and sells the complete inventory of support system at the same time the air-

While the aerospace engineer of today knows that support systems are using an increasing portion of a weapon system budget, he may not be acquainted with such things as definitions of GOE, GSE, GSME, facilities, etc., and how these things are provisioned. Nor may he know how requirements for these support items are normally generated. This article provides some of these definitions, describes some of the typical provisioning procedures, and emphasizes the requirement that a support system be consistent with an overall logistics plan derived after a comprehensive operational analysis. The interrelation of requirements, plans, designs, etc., points out the obvious efficiency gained by identifying one contractor, preferably the airframe contractor, as the integrating support system contractor. It is important to note that support system design does not push the state of the art to the degree demanded by some of the modern airborne systems. Support system designed at this time should be more concerned with man-machine relations; importance of coordination and standardization of individual designs for color, power, structural factor of safety, and expected life; and environmental considerations.

Techniques for selection of standard military equipment, commercial equipment, and special equipment are discussed. Time phasing for preparation of support system plan, provisioning, design, fabrication, and activation—in relation to the total weapon system readiness period—is reviewed.

The overall state of the art in support systems is identified. Techniques available and used today by the aerospace support system engineer in several major categories—including underground installations, launchers, erectors or cranes, propellant loading, launch control and checkout, fire fighting, umbilical lines, flame deflectors, transporation, etc.—are included.

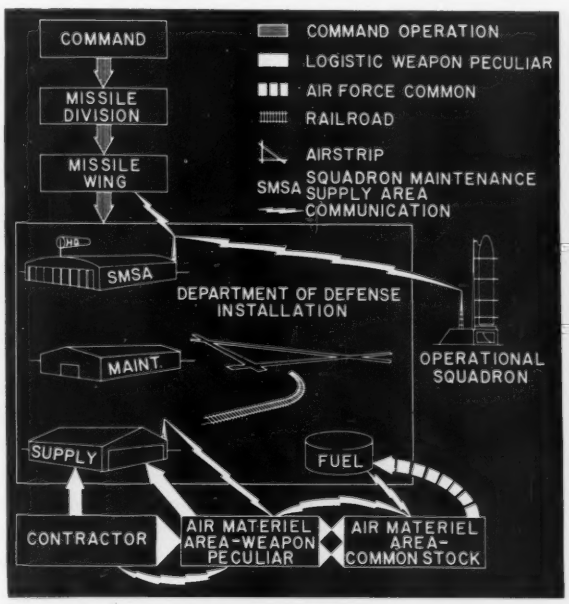
borne system is contracted. However, the basing concept is an indispensable part of the complete system plan and is usually part of the initial proposal. In most cases, the customer identifies the basing plan. For instance, proposal requests may be issued to industry for a new missile to be fired from the wing of a specific military airplane, from the deck of a Navy cruiser, or from a fixed underground installation. In other cases, industry proposes basing concepts and weapon systems to a customer in solution to a strategic or tactical military requirement. In both events only the concept is normally identified. Detail identification of support system equipment and facilities is left for development after the initial prime contract is awarded. Detail requirements can be identified only as the airborne system support needs are identified.

Of course, the customer wishes that his airborne system could operate with little or no support system but, recognizing that there must be some bare minimum, wishes to keep the cost low, the reliability high, and the personnel required to operate it at a minimum. Usually the customer will not, and should not, buy an airborne concept unless he also buys a support system concept.

In some cases, however, the support system itself is most important. For instance, if the prime requirement for a weapon system is survival under enemy attack, then it is vital to spend whatever money is needed to build the support system that will provide survival for the weapon. Our underground "hard-based" ICBM's are in this category. These fixed site missiles are of little value unless they survive an enemy attack or take off before an attack

The support system concept should define the entire logistic and maintenance plan for the operational system. It should include the proposed method of transportation, flow of spares, levels of maintenance, number of personnel and their skill level, chain of command, communication network, commodity supply plan, etc. Fig. 1 illustrates a typical weapon support system logistic and maintenance concept flow diagram. A diagram of this type helps the support system engineer

Fig. 1. Typical support system flow diagram.



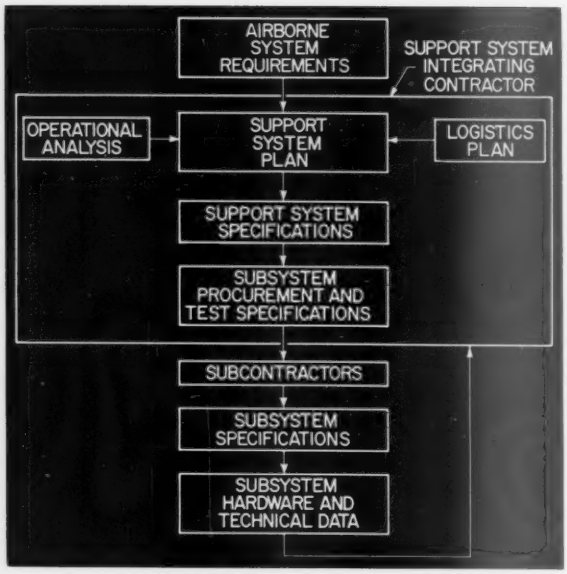


Fig. 2. Flow of data and equipment.

understand the need for equipment and facilities at all locations involved for an operational weapon. It pictorially shows the location of missiles and associated facilities and, when used with the actual distances involved, expedites determination of maintenance levels assigned to each area.

Detail requirements for ground equipment usually develop during design of the airborne system. The proposal may have noted, for instance, that the missile would be fueled with liquid propellants of a minimum specific impulse. When the actual liquids are identified, certain temperature limits may be required at all times to prevent freezing or boiling. Then, and only then, can the type of equipment required for this purpose be identified. Perhaps the designer has a choice. Perhaps the shelter in which the missile is based already provides proper temperature control. If not, then its planned heating and ventilating equipment can be easily modified to meet requirements, or, at worst, a special piece of equipment can be provided to give the missile propellants their required environment.

In many cases, ground considerations dictate airborne design. Reaction time may determine the type of propellent to use, or launch stand stiffness may influence airframe structure.

The important point is that a requirement for support equipment must be identified by the designers of both airborne equipment and ground systems. The support system designer considers this requirement and integrates it into a support system concept. At this point the support system designer plays his most influential role. He may be able to point out to the airborne system designer—for instance—that, were a hydraulic actuator changed to an electrically powered screw jack, an entire ground hydraulic power supply could be eliminated, and the electric power load could be absorbed in an existing electric power supply during low demand.

Fig. 2 illustrates the flow of data and equipment. It shows how the airborne requirements, the logistic plan, and the operational analysis make up the master support system plan. This plan usually defines the broad overall concept. A more detailed and specific support system specification is derived from the master plan. This specification gives quantitative data: It may state that six 28±1/2-volt d.c. generators be provided, or that the missile be hauled on one 6 by 6-ft. truck per MIL-M-1090A, Type III mobility. From the support system specification comes a set of individual procurement and test specifications directed at subcontractors or at special skill design groups within the integrating contractor's own organization. The selected subcontractor for a specific subsystem, such as an air conditioner, then designs, manufactures, tests, and delivers his item along with engineering drawings and the system specification to his customer, the integrating contractor. The integrating contractor then installs and interconnects the subsystems and activates the entire support system for the customer.

Support System Time Phasing

As previously shown, a complete definition of support system equipment and facilities is impossible before airborne requirements are known. Obviously, the airborne system cannot be used until its support system is manufactured, installed, and activated. Fig. 3 illustrates the relatively short time span available for design, procurement, manufacturing, and activation of the support system. The time may be even shorter if the GSE is required in the factory as part of the manufacturing or laboratory test function.

The support system designer is perhaps fortunate that he has comparatively few technical breakthroughs, generally a simple drawing system, and uses a maximum amount of standard military and commercial equipment. He must guard against unjustified airborne requirement changes that tend to delay and add cost to his ground system. He should question the weapon system gain, if any, in making the change. He is also fortunate in his ability to provide high structural safety factors and good reliability without worrying about a weight penalty on performance. Of course, the support system designer should always design for economy by efficient selection and arrangement of structural material; he should consider the cost of labor, as well as material, and liberalize manufacturing tolerances to the maximum extent. His most important duty is to find ways to eliminate himself from business by always question-

ing the requirement generated by the airborne system. The customer wants more weapons for his money; he does not really want to buy support equipment or facilities. He would like to drive up to the gas pump, like the World War II bomber, load up and take off.

Provisioning Procedures

Provisioning of support systems in the past has been influenced by budgetary considerations. Facilities have, by tradition, been paid for from one budget and usually fall under the cognizance of the U.S. Army Corps of Engineers if the project is Army or Air Force, or under the Bureau of Yards and Docks if the project is Navy. Facility design, by law, must be done at cost to the Government. The airborne system and the GOE-GSE, all being severable or mobile, are provided as part of the supply contract between the customer and the contractor. When fighting for time, a contractor will resent the delays usually associated with the involvement of the customer's construction agency, no matter how efficient that operation may be. Contractors have been known to stretch the point and put wheels on what otherwise would be a facility and call it GSE, or to package a pumping station and mount it on skids just to speed up procurement and, needless to say, make a profit on its design.

The customer, not having a detail identification of equipment and facilities when he awards a prime contract to a contractor, insists on approving these items individually before he contracts for their procurement. The contractor, as he identifies a requirement for a certain item of GSE should, therefore, present the recommended solution and a budgetary cost to the customer. The GSE must be consistent with the support system plan and should not be of new design if standard or economically modified commercial or military equipment will suffice.

A tool he sometimes uses is a description and utilization sheet (D&U sheet). This form states the problem, the recommended solution, and the quantity and location of the equipment required. From the D&U sheet may evolve formal contractual provisioning papers. Some of the quantity may be deliverable items—i.e., one is required as part of the operational missile system. Some may be nondeliverable—i.e., they may be required and used by the contractor in his factory or during his research and development testing program, and will never see operational use. Here again, budget dictates. A contract may distinguish between deliverable and nondeliverable equipment. The contractor has no legal right to do detail design until he has customer approval. The customer, as well as the contractor, searches existing stock for equipment to satisfy the requirement. If there is no satisfactory equipment, he then gives his approval for the contractor to proceed with design and procurement.

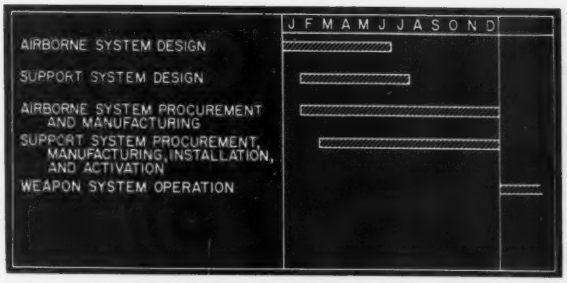

J F M A M J J A S O N D
AIRBORNE SYSTEM DESIGN
SUPPORT SYSTEM DESIGN
AIRBORNE SYSTEM PROCUREMENT AND MANUFACTURING
SUPPORT SYSTEM PROCUREMENT, MANUFACTURING, INSTALLATION, AND ACTIVATION
WEAPON SYSTEM OPERATION

Fig. 3. Time phasing.

Sometimes the customer and the contractor will hold "provisioning conferences" where decisions on GSE are made. To save time, and only when no satisfactory design exists, the contractor may authorize his engineering personnel to proceed with design in anticipation of customer approval.

Guiding Philosophies

The support system engineer is guided by several major influencing factors—reliability, economy, simplicity, time phasing, state of the art, operational analysis, and logistic plan. Weapon system efficiency, therefore, requires real support system integration on the detail planning and design levels. Integration can be accomplished only by identifying one agency, preferably the airframe contractor, as the integrating support system contractor.

State of the Art

Today the support system engineer finds himself in the position of designing systems representing a major portion of weapon system procurement cost. He works with techniques generally within the state of the art. He is limited on time in which to accomplish his job. He must assimilate a mass of detail and integrate it into a clear, precise plan, and with equipment easily operated by the customer's personnel.

In spite of some difficulties, today he finds himself able to handle cryogenic or toxic fluids, to transport exceedingly large or heavy shapes, and to count down and launch any airborne system yet devised. He looks to the future with great optimism that he will still be able to support any potential system we may desire to operate.

(Part II of this series will appear in the September issue, Part III in November.—Ed.)

An attempt is made to find the most favorable speed-altitude schedule for a supersonic transport or bomber, with minimum shock-wave noise as the prime consideration. The propagation of shock waves is discussed for the case of a homogeneous atmosphere and also for a normal atmosphere exhibiting temperature and wind gradients. The most recent experimental results and the available theory concerning the "sonic boom" are discussed.

SONIC BOOM—Limitations on supersonic aircraft operations

Donald W. Patterson, AIAS, Convair, A Division of General Dynamics Corporation

THE SONIC BOOM, which appeared with the advent of supersonic flight by operational aircraft, was first recognized as an interesting phenomenon. Now, as the seriousness of the boom problem is realized, it must definitely be taken into operational and design considerations. While the boom does not aerodynamically affect the aircraft's performance, it does have an extreme effect on the aircraft's acceptance by the general public.

With public irritation and property damage causing complaints to be made daily to airports, Air Force bases, and manufacturers, the noise problem is not one which can be taken lightly. With supersonic aircraft becoming more common, it is obvious that steps must be taken to combat the situation. While the operational capabilities of military aircraft must not be hampered in time of emergency, they can, on the other hand, be limited in routine maneuvers in populated areas. Similarly, the capabilities of commercial aircraft will be limited by the tolerance of the neighborhoods surrounding the airports and beneath the air lanes.

Basic Phenomena

An aircraft in supersonic flight will form a shock-wave formation which may extend to the ground and cause a sonic boom. The sharp increase in pressure which characterizes the shock wave as it passes an observer is interpreted by the ear as an explosion. The intensity of the noise can be theoretically calculated in terms of pressure rise and converted to decibels.

Symbols

- d = equivalent body diameter, ft.
- db = decibels
- h = altitude, ft.
- K_1 = ground-reflection factor
- K_2 = airplane body shape factor
- l = airplane length, ft.
- M = airplane Mach number
- P_a = ambient pressure at altitude, lbs./sq.ft.
- P_0 = ambient pressure at ground level, lbs./sq.ft.
- P_1 = base reference pressure, lbs./sq.ft.
- Δp_0 = pressure rise across shock wave at ground level, lbs./sq.ft.
- T = temperature, °R.
- W = wind velocity, knots
- w = power unit
- y = perpendicular distance from observer to flight path, ft.
- γ = flight path angle, deg.
- μ = Mach angle, $\sin^{-1}(1/M)$

A widely used method of estimating the pressure rise was originally presented in reference 1 and may be conveniently written as

$$\Delta p_0 = K_1 K_2 \left(\frac{\sqrt{P_a P_0}}{y^{3/4}} \right) (M^2 - 1)^{1/8} \left(\frac{d}{l} \right) l^{3/4} \quad (1)$$

Eq. (1) assumes a homogeneous atmosphere, no wind or temperature gradient, and does not account for airplane lift, deviation from steady level flight, and

Mr. Patterson received his B.S. degree in aeronautical engineering from the Pennsylvania State University in 1957. He has done graduate work toward a Master's degree in engineering through the University of California at Los Angeles. As an aerodynamics engineer at Convair, Mr. Patterson has been closely associated with the firm's jet transport projects and is now responsible for the flight predictions of the stability and control of the Convair 600. He is a member of Omicron Delta Kappa and Sigma Tau and an Associate of the IAS.

propagation losses in the atmosphere. As an example, the pressure rise can be calculated for the following conditions:

Reflectivity factor $K_1 = 2$ — Altitude 30,000 ft.
Body shape constant $K_2 = 0.6$ — Mach $M = 2$
Fineness ratio $l/d = 12$
Length of aircraft $l = 180$ ft.
Observer directly under flight path

$$\Delta p = (2)(0.6)\left(\frac{\sqrt{(628)(2116)}}{(30{,}000)^{3/4}}\right)(4-1)^{1/8} \times \left(\frac{1}{12}\right)(180)^{3/4}$$

$$= 1.2\left(\frac{1{,}150}{2{,}277}\right)(1.147)(0.0833)(49) = 2.84 \text{ lbs./sq.ft.}$$

The results of calculations of this type are presented in Fig. 1 as a function of altitude, with Mach number as a parameter. It is apparent that altitude, not Mach number, is the prime factor in the magnitude of the shock noise at the ground level. The theory seems consistently to overestimate the pressure on the ground according to data in references 2, 3, and 4. Support for this statement can be seen in Fig. 2, which is based on reference 2. A portion of the discrepancy may be caused by the fact that the theory is based on slender bodies.[4] Adjustments can be made for this error in several ways, the easiest being a reduction in the reflectivity and body shape constants. The reflectivity factor varies from 1.0 to 2.0 and will be the maximum for a hard, flat surface. The body shape factor depends upon the location of the maximum thickness of an equivalent body as shown in Fig. 3, which was originally presented in reference 2.

The National Aeronautics and Space Administration (NASA) has published[2] the interesting data shown in Table 1.

The conversion to decibels can be made simply by the expression

$$db = 10 \log_{10}(w_1/w_2) \qquad (2)$$

where w_1/w_2 is a power ratio. The pressure can be expressed as the square root of the corresponding power ratio so that

$$db = 20 \log_{10}(\Delta p_0/P_1) \qquad (2a)$$

where the base reference pressure P_1 is often given the value 0.4178×10^{-6} lbs./ft.^{2} which corresponds to the threshold of hearing. To convert 1.0 psf to decibels,

$$db = 20 \log_{10}[1/(0.4178 \times 10^{-6})] = 20 \log_{10}(2.4 \times 10^6)$$
$$= 20\ (6.38)$$
$$= 128$$

In order to improve our "feel" for sound intensity levels, a common type of noise table is recalled from reference 5 (see Table 2).

The number of booms which are heard depends on the number of shock waves which reach the ears of the observer. It is possible to distinguish two booms from a single aircraft. The first boom would be the result of the bow wave and the second the result of the tail wave. There is some indication that a time interval of $^1/_8$ sec.

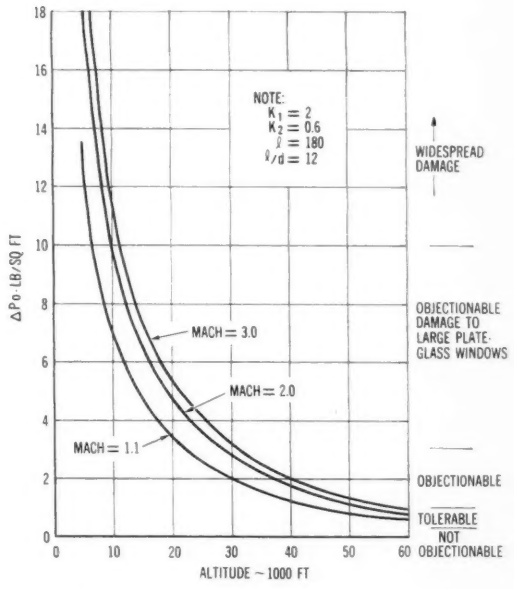


Fig. 1. Calculated pressure rise, ground level.

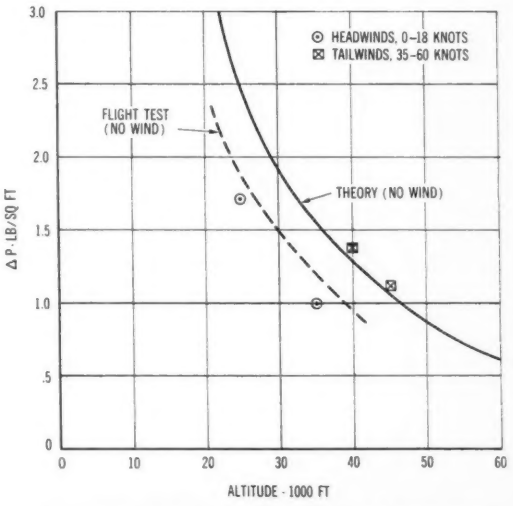


Fig. 2. Pressure rise on the ground ($M = 1.3$, $l/d = 7.7$).

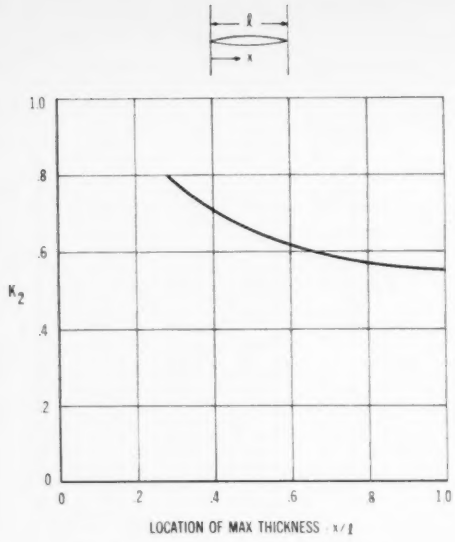


Fig. 3. Calculated effect of body shape.

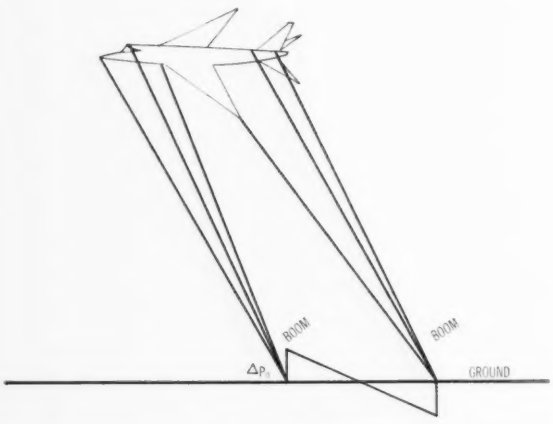


Fig. 4.

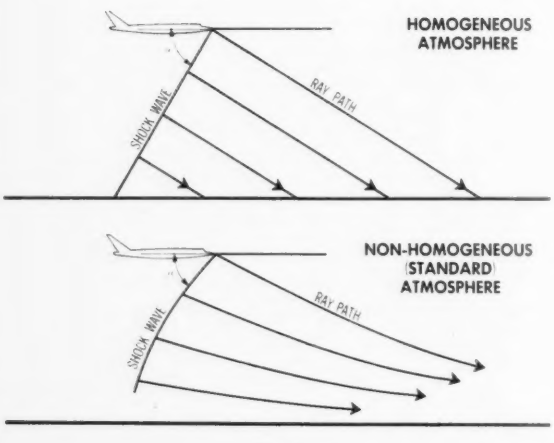


Fig. 5.

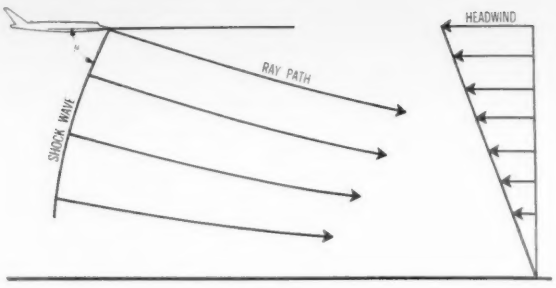


Fig. 6.

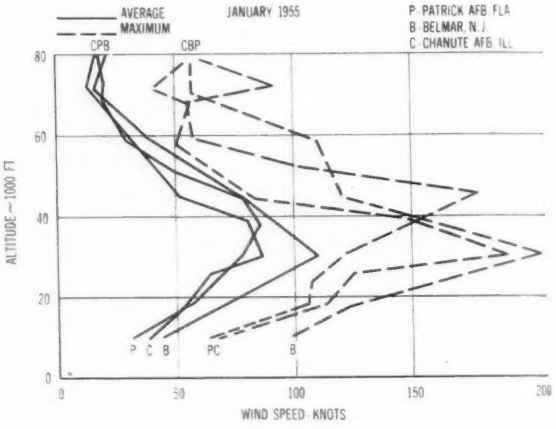


Fig. 7. Wind speeds.

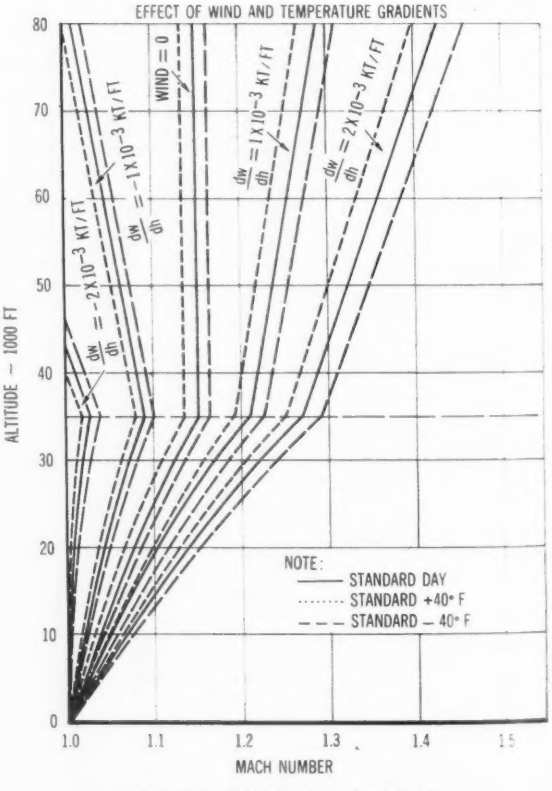


Fig. 8. Cutoff Mach number, level flight.

between the waves is necessary for the discrimination of two sounds.[3] Intermediate waves from the wing, canopy, etc., merge with the strong compression shock waves of the bow and tail and are normally not heard. (See Fig. 4.)

Nonhomogeneous Atmosphere

In a nonhomogeneous atmosphere, Eq. (1) is not quite valid. There are two factors, temperature and wind gradients, which have a pronounced effect on the sonic boom. A simple method of looking at shock-wave behavior due to these gradients is the ray path concept. In a homogeneous atmosphere, the shock wave generated by a supersonic aircraft would be a straight line extending to the ground at the Mach angle μ. The direction of travel of the wave would be normal to the shock front along what is called a ray path, and the velocity would be a function of the speed of sound which is a constant in this ideal atmosphere.

However, since the speed of sound increases with decreasing altitude in standard atmosphere, the shock wave tends to propagate faster as it approaches the ground. By looking at the ray path diagrams in Fig. 5, we can see that this temperature effect will bend the shock wave forward and the ray path upward.

It is possible for the downward component of the shock front velocity vector to become zero. If the aircraft is flying at low supersonic Mach numbers, it is reasonable to predict that the shock wave will cease to travel toward the ground, and, as a result, no sonic boom would be heard. Consider the limiting Mach number, or "cutoff" Mach number as it is verbally referred to by the NASA, at some altitude—35,000 ft., say. At this altitude, the Mach number would be approximately 1.15, which happens to be 660 knots, the sonic velocity at sea level. In this case, the shock wave becomes weaker and weaker as it approaches the ground and finally ceases to exist. No sonic boom is heard!

A wind gradient can have the same type of effect on the shock wave. A favorable effect will occur in the case of a headwind increasing with altitude (see Fig. 6). The relative velocities can be supersonic at altitude and yet slightly subsonic at the ground level, and the result is most encouraging. No sonic boom!

While no sane pilot will search for strong headwinds in the cruise portion of his flight, he will—having no alternative except to fly into the wind—have the wind

Table 1. Shock-Noise Phenomena

p (lbs./ft.^{2})	p (db)	Resulting Physiological Reaction	Associated Physical Phenomena
0.1–0.3	108–118	Not objectionable	Barely audible explosion
0.3–1.0	118–128	Tolerable	Distant explosion or thunder
1.0–3.0	128–138	Objectionable	Close-range thunder, some window damage
3.0–10.0	138–148	Objectionable	Damage to large plate-glass windows
10.0–30.0	148–158	Objectionable	Definite damage to small barracks-type windows

Table 2.

Source or Description of Noise	Noise level, db
Threshold of hearing	0
Rustle of leaves	10
Average whisper	20
Quiet radio in home	40
Quiet automobile	50
Ordinary conversation	65
Busy street traffic	70
Elevated train	90
Riveter	95
Threshold of pain	120
Jet engine in test cell	160

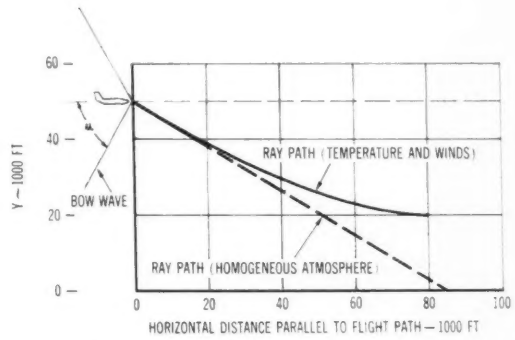


Fig. 9. Calculated ray paths of bow-wave propagation ($M = 1.15$).

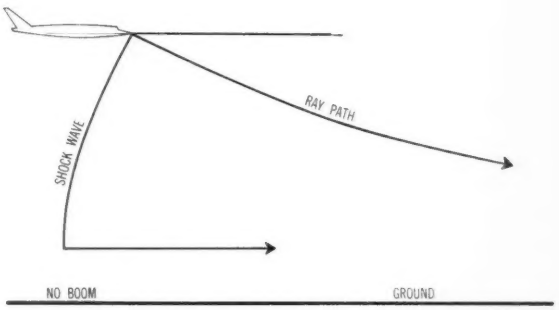


Fig. 10.

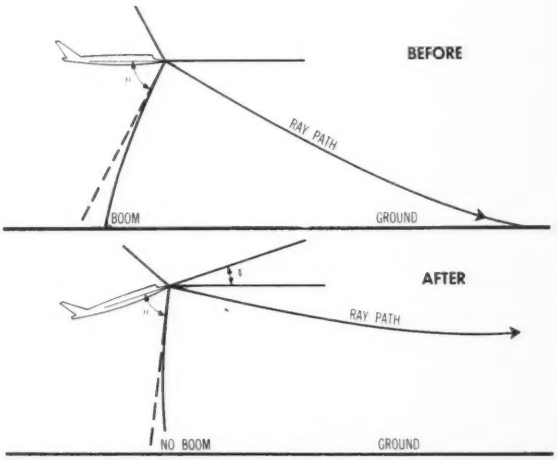


Fig. 11.

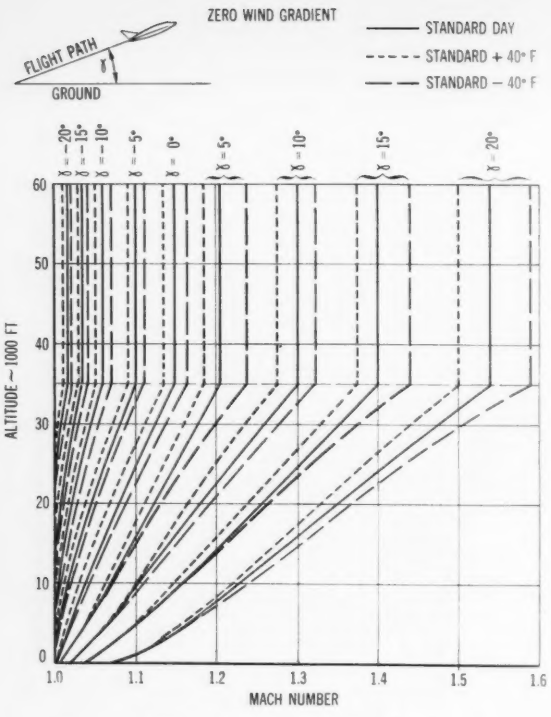


Fig. 12. Cutoff Mach number, effect of flight path angle.

gradient effect on sonic boom as his consolation. Headwinds are an asset here, but tailwinds are just as much of a liability. This aspect would be aggravating for an aircraft flying west to east in the 150-knot jet stream, but the supersonic transports will, for the most part, be flying at altitudes above these swift air currents. Data from reference 6 have been used to show typical wind velocities at various altitudes in Fig. 7.

The combination of the temperature and wind gradient effects is presented in Fig. 8. Note that the favorable temperature effect reaches a maximum at 35,300 ft. (tropopause) and remains constant above that altitude.

Fig. 9, which has been taken directly from the flight-test data of reference 3, offers proof that the wind and temperature gradients can be depended upon to cause the sonic boom to miss the ground. The airplane being tested was a century-series flighter being flown at $M = 1.15$, at an altitude of 45,000 ft., in the presence of a headwind.

Climb Path Angle

Another variable which can be considered in the investigation of the sonic boom is the airplane attitude. While there are no actual published data available to the author's knowledge, a prediction can be made of the effect of climb path and glide path. As the departure is made from level flight, the shock-wave pattern will tend to rotate with the airplane and remain nearly symmetrical with the flight path. In the case of a climb path angle, this characteristic should be helpful in avoiding a sonic boom on the ground. The angle being discussed is not to be confused with angle of attack, which has a slightly detrimental effect. By looking at the situation from a strictly geometrical standpoint, we can approach the problem with the aid of the ray path diagrams in Figs. 10 and 11. It is known that a shock-wave front ceases to travel toward the ground to cause a sonic boom as soon as the wave reaches a vertical orientation in the atmosphere.

If the climb path angle can be used legitimately to rotate the shock wave, it will be possible to fly at higher Mach numbers at a certain altitude without causing a sonic boom to occur on the ground—i.e., to increase the cutoff Mach number.

This concept is powerful enough to change the cutoff Mach number at 35,000 ft. from 1.15 to 1.57 for a climb path angle of 21°. By taking advantage of this prediction, the engineer can plan on using considerably more of his available performance capabilities during the climb, one of the most important stages of the flight. Of course, the flight path angle during descent causes an opposite effect on the ground which probably had much to do with the fact that sonic booms were heard as early as 1950 from aircraft which were slightly supersonic in a dive. This opposite effect may make it necessary to decelerate to transonic speeds before descending below 50,000 ft. However, this should have practically no adverse effect on range and payload since it will not be necessary for the pilot to fly the aircraft at maximum speeds during this phase of the flight.

The predicted effect of flight path angle on cutoff Mach number is presented in Fig. 12 as a function of altitude for standard, hot, and cold days. Fig. 13 is a summary plot showing the combined effects of altitude, winds, and flight path angle on cutoff Mach number.

The validity of the climb path concept will be discussed in a later paper when experimental data are available to make comparisons. In a telephone conversion with Harvey Hubbard, NASA engineer at Langley Field, Va., it was learned that climb path angle does affect to some extent the cutoff Mach number and that reports concerning this subject will be forthcoming in the near future.

(*Continued on page 44*)

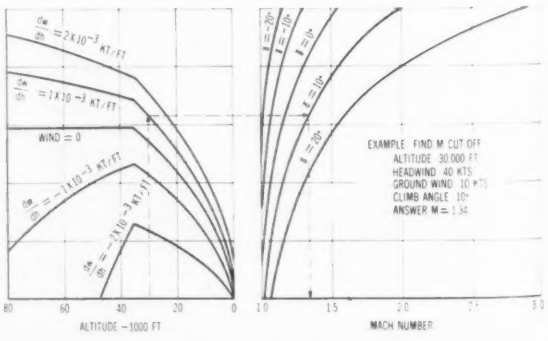


Fig. 13. Cutoff Mach number, standard day.

Stiffness matrices previously developed are used in the analysis of complex wing structures. Favorable statistical comparisons of measured and analytical influence coefficients are presented for a swept wing involving intermediate stiffeners and multispar design. Excellent comparison of vibration mode shapes and frequencies is shown. Analysis results for a biconvex wing with a coarse nodal network are compared favorably with an analog solution.

Prediction of Flexibility and Natural Modes of Low Aspect Ratio Wings Using Stiffness Matrices

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Boeing Airplane Company, Aero-Space Division

CONTINUING EFFORT in extending and applying the method of direct formulation of the stiffness matrix from component stiffness matrices has shown it to be versatile, reliable, and accurate in predicting structural behavior. In reference 1, the method is aptly described, and stiffness matrices for a triangular plate, elementary beam spar (or rib), and stringer are developed. In reference 2, a spar matrix based upon the superposition of strain states associated with uniform shear and a constant moment is presented which has superior convergence characteristics for structures whose spars and ribs are principally shear carrying members.

Examination of the theoretical bases of the plate, beam, and a stringer matrices will convince the reader that these include the principal modes of elastic behavior and inherently account for those effects termed shear lag, shear deformation, and Poisson's ratio coupling. No restrictions are imposed with regard to orientation of the structural components. Thus, in an analysis, prejudgments about "effective" material are obviated and sweep and taper do not restrict the approach. It is important to recognize that the guiding philosophy of the analysis is to analyze the structure with various degrees of nodal refinement and use the comparison between answers as the measure of analytical accuracy.

Application of the method in references 1 and 2 has been to unswept, untapered, cantilevered box beams. It is the purpose of this paper to demonstrate the application of the method to more practical structures in which the problems of sweep, taper in planform and depth, and a complex arrangement of internal members are present. Two examples have been chosen. The first is an untapered multispar swept wing involving intermediate skin stiffeners and multipoint support. To demonstrate convergence, solutions are obtained for two nodal refinements. Statistical comparisons are furnished between analytical and experimental influence coefficients. Measured and predicted natural

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Mr. Merritt is Chief of the ASW/USW Structures Unit. He has specialized in dynamic loads, aeroelastic instabilities, and deflection analyses of missile and aircraft structures. He has participated in the development of the stiffness method and in developing design techniques for low- and high-speed wind-tunnel flutter models. He was graduated from Yale in 1950. In 1951, he received his M.S. in Civil Engineering and in 1953 the degree of Civil Engineer, both from the California Institute of Technology.

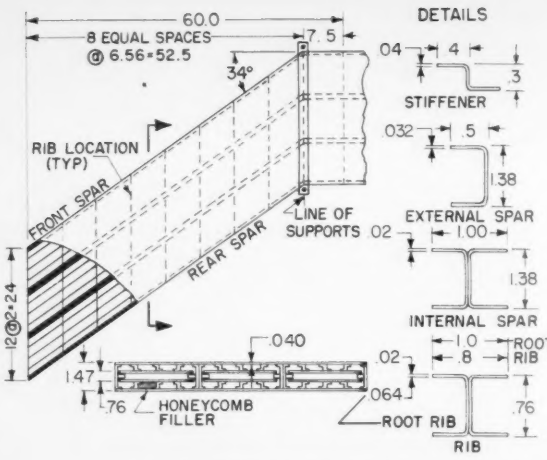


Fig. 1. Untapered wing geometry.

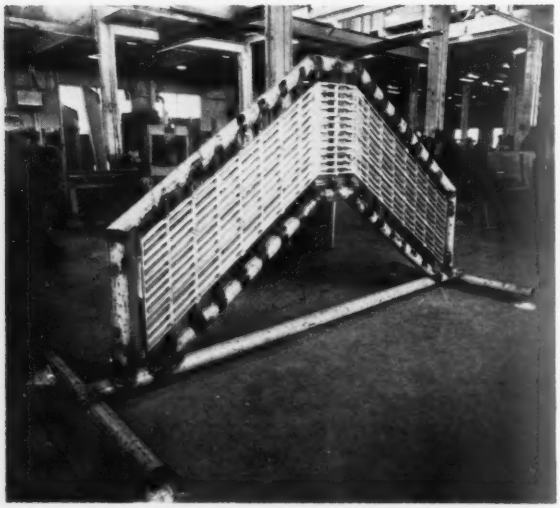


Fig. 2. Assembly fixture and framework, model wing.

frequencies and mode shapes are also compared. The second is a biconvex multispar delta wing on a continuous support. The accuracy of the analysis with a coarse network is shown by comparisons between measured influence coefficients and analog computer influence coefficients, natural frequencies, and normal mode shapes.

Untapered Multispar Wing: Geometry

The geometry and structural layout of this wing is shown in Fig. 1. A photograph of the internal structure in its final assembly fixture is shown in Fig. 2. All components of the multispar wing were fabricated from 2024-T3 material except the fillers inserted between the ribs and skins to provide a shear tie. These fillers consisted of aluminum honeycomb with cells filled with a plastic resin.

Boundary Conditions and Loading

The model wing was supported at four points top and bottom along each root chord to simulate typical fuselage fixity. Supports were located at the intersections of spars and ribs and provided vertical restraint only. Fixtures for static loads were provided at the intersections of spars and ribs over the whole wing as shown schematically and numbered in Fig. 3.

Assumptions for Analysis

Two nodal networks were selected to provide a measure of solution convergence independent of test results. These consisted of the 28- and 133-nodal patterns shown in Fig. 3. In both analyses the skin and stringer stiffness matrices of reference 1 and the shear moment spar matrix of reference 2 were used. Zero vertical displacements were specified at the support points and along the centerline of the beam, the bending slope was fixed at zero. Rigid body translation in the chordwise direction was prevented.

The machine program combined the stiffness matrices and performed a matrix inversion to obtain influence coefficients for the loads and vertical displacement at the 16 loading points. These data are given in Tables 2 and 3 for the 28- and 133-node networks, respectively. Masses were assumed lumped at these same 16 points in determining mode shapes and frequencies. Rotary inertias were neglected. Mode shapes and frequencies are given in Figs. 4 and 5. The first three modes obtained analytically were essentially identical with those measured and are not given here.

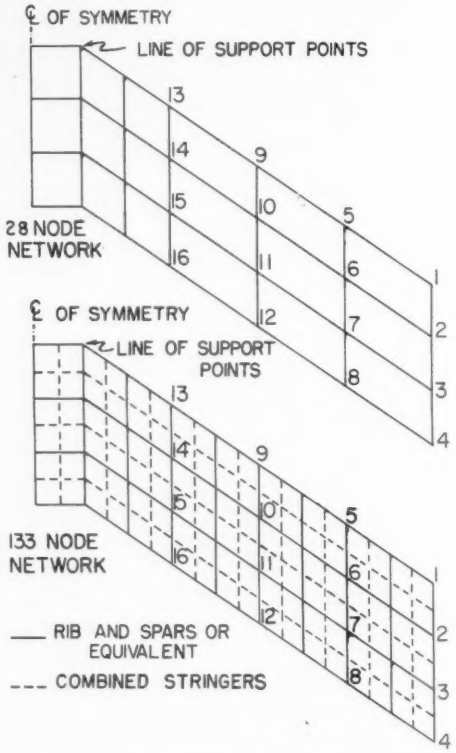


Fig. 3. Analytical nodal networks.

Table 1. Untapered Multispar Wing—Static Test Influence Coefficient Matrix

Load Points	Deflection Points 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	6.45	6.67	6.96	7.22	4.02	4.38	4.70	4.95	1.96	2.26	2.53	2.75	0.531	0.716	0.975	1.01
2		7.26	7.80	8.33	4.03	4.64	5.16	5.63	1.91	2.36	2.74	3.13	0.492	0.711	0.933	1.16
3			8.71	9.55	4.16	4.93	5.67	6.42	1.88	2.43	2.99	3.50	0.447	0.715	0.996	1.31
4				10.8	4.20	5.18	6.18	7.17	1.86	2.54	3.22	3.94	0.402	0.716	1.05	1.46
5					2.74	2.82	2.90	2.97	1.44	1.58	1.65	1.70	0.416	0.528	0.599	0.656
6						3.14	3.44	3.64	1.41	1.68	1.90	2.10	0.378	0.539	0.669	0.820
7							3.94	4.38	1.38	1.77	2.14	2.54	0.339	0.538	0.739	0.985
8								5.12	1.35	1.83	2.35	2.91	0.301	0.542	0.806	1.13
9									0.933	0.886	0.859	0.817	0.316	0.358	0.354	0.341
10										1.00	1.07	1.12	0.272	0.361	0.418	0.472
11											1.32	1.48	0.233	0.358	0.480	0.626
12			Symmetric									1.84	0.189	0.349	0.527	0.760
13													0.232	0.162	0.122	0.089
14														0.196	0.177	0.168
15															0.250	0.281
16																0.446

Deflections in in./1,000 lbs.

Static and Dynamic Model Test

The wing was subjected to extensive static and dynamic testing. Static deflections were measured at the 16 stations corresponding to the analysis for pairs of loads placed symmetrically about the centerline. Deflection readings were taken during the loading and unloading parts of the cycle. Reducing these data, a 16 by 16 matrix of influence coefficients was generated. Because of inelastic structural behavior, this matrix was not symmetric as required by Maxwell's reciprocity theorem. Because of the smallness of the error, it was considered sufficiently accurate to average the C_{ij} and C_{ji} elements to obtain the symmetric matrix shown in Table 1. Ninety-three per cent of the elements of this

Table 2. Untapered Multispar Wing—Analytical Influence Coefficient Matrix

Deflection Points 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Load Points
5.97	6.18	6.38	6.57	3.69	3.98	4.22	4.43	1.75	2.01	2.24	2.43	0.474	0.624	0.745	0.844	1
	6.70	7.18	7.64	3.72	4.20	4.67	5.13	1.70	2.07	2.44	2.81	0.432	0.615	0.793	0.977	2
		7.99	8.78	3.75	4.43	5.12	5.85	1.65	2.13	2.64	3.18	0.391	0.607	0.841	1.110	3
			10.02	3.78	4.65	5.57	6.57	1.60	2.19	2.84	3.55	0.349	0.598	0.889	1.24	4
				2.51	2.55	2.59	2.62	1.29	1.40	1.46	1.51	0.379	0.469	0.524	0.552	5
					2.81	3.02	3.24	1.24	1.46	1.67	1.87	0.338	0.460	0.573	0.686	6
						3.47	3.90	1.19	1.52	1.87	2.24	0.296	0.451	0.621	0.820	7
							4.62	1.14	1.58	2.07	2.62	0.254	0.443	0.669	0.953	8
								0.815	0.774	0.731	0.686	0.289	0.310	0.299	0.271	9
									0.863	0.915	0.968	0.242	0.306	0.352	0.391	10
										1.11	1.29	0.200	0.296	0.402	0.525	11
		Symmetric									1.66	0.158	0.287	0.448	0.665	12
												0.182	0.136	0.100	0.066	13
													0.158	0.143	0.131	14
														0.193	0.222	15
															0.358	16

Deflections in in./1,000 lbs., 28-node solution.

Table 3. Untapered Multispar Wing—Analytical Influence Coefficient Matrix

Load Points	Deflection Points 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	6.39	6.61	6.82	7.04	3.98	4.29	4.54	4.78	1.92	2.20	2.44	2.65	0.526	0.689	0.823	0.936
2		7.16	7.64	8.12	4.02	4.53	5.02	5.49	1.87	2.26	2.65	3.04	0.481	0.681	0.875	1.08
3			8.49	9.29	4.05	4.76	5.48	6.23	1.82	2.33	2.86	3.43	0.435	0.673	0.927	1.22
4				10.57	4.09	4.99	5.95	6.98	1.77	2.39	3.07	3.82	0.390	0.665	0.979	1.36
5					2.77	2.80	2.84	2.88	1.43	1.55	1.63	1.68	0.423	0.520	0.584	0.623
6						3.07	3.29	3.52	1.38	1.62	1.84	2.05	0.378	0.512	0.637	0.763
7							3.77	4.21	1.32	1.68	2.05	2.44	0.332	0.504	0.689	0.904
8								4.96	1.28	1.74	2.26	2.83	0.287	0.496	0.741	1.05
9									0.934	0.880	0.834	0.790	0.322	0.349	0.344	0.320
10										0.984	1.03	1.09	0.274	0.345	0.400	0.448
11			Symmetric								1.25	1.44	0.228	0.336	0.453	0.588
12												1.84	0.183	0.327	0.502	0.732
13													0.218	0.160	0.119	0.081
14														0.189	0.167	0.155
15															0.229	0.257
16																0.412

Deflections in in./1,000 lbs., 133-node solution.

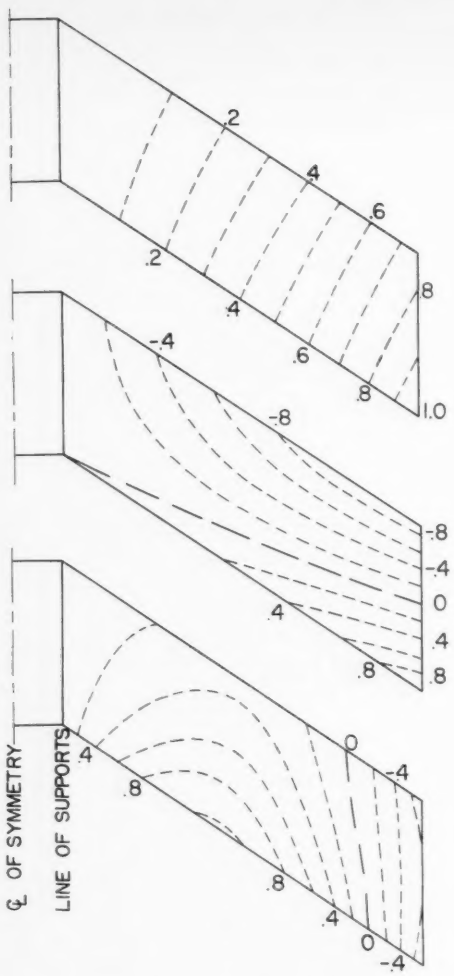


Fig. 4. Untapered wing mode contours.
(*Top to bottom:* First mode shape—test 7.47 cps, analysis 7.56 cps; second mode shape—test 27.6 cps, analysis 27.1 cps; third mode shape—test 45.3 cps, analysis 45.3 cps.)

matrix differ from the measured values by less than 3 per cent. Only one of the off-diagonal elements differs by more than 5 per cent.

Normal vibration modes were excited by four electromagnetic shakers arranged symmetrically, two on each half of the wing. Resonance was determined by the phasing between velocity and shaker force at the voice coils. The experimental work included determination of the first five symmetrical mode shapes and frequencies. In addition to dead weight, masses were located at 8 of the 16 load points. These masses took the form of hemispherical domes of lead weighing 2.5 lbs. each and fastened to the top and bottom surfaces at the required points. The value of the mass to lump at each station was obtained by calculating the mass in regions bounded by a grid formed of lines bisecting the internodal distances. The elements of the diagonal mass matrix in lb. sec.^{2} per inch associated with Tables 2 and 3 are 0.01427, 0.00243, 0.00243, 0.01427, 0.01560, 0.00488, 0.00488, 0.01560, 0.01568, 0.00504, 0.00504, 0.01568, 0.01576, 0.00520, 0.00520, and 0.01576.

Comparison of Analysis and Experiment

A statistical comparison of analytical and experimental influence coefficients is given in Table 4. The negative signs here indicate that the analysis predicts greater stiffness than that measured. This might have been anticipated using the shear-moment spar matrix in accordance with the remarks in reference 2.

A comparative summary of resonant frequencies is given in Table 5. The reader can compare mode shapes of the wing by reference to Figs. 4, 5a, and 5b.

Tapered Delta Wing: Geometry

The geometry and structural layout of a hypothetical wing is shown in Fig. 6. The wing is assumed to be fabricated of aluminum ($E = 10.4 \times 10^6$, Poisson's ratio 0.30).

Boundary Conditions and Loading

This wing is supported by a continuous simple support along the sides of the fuselage. Static loads

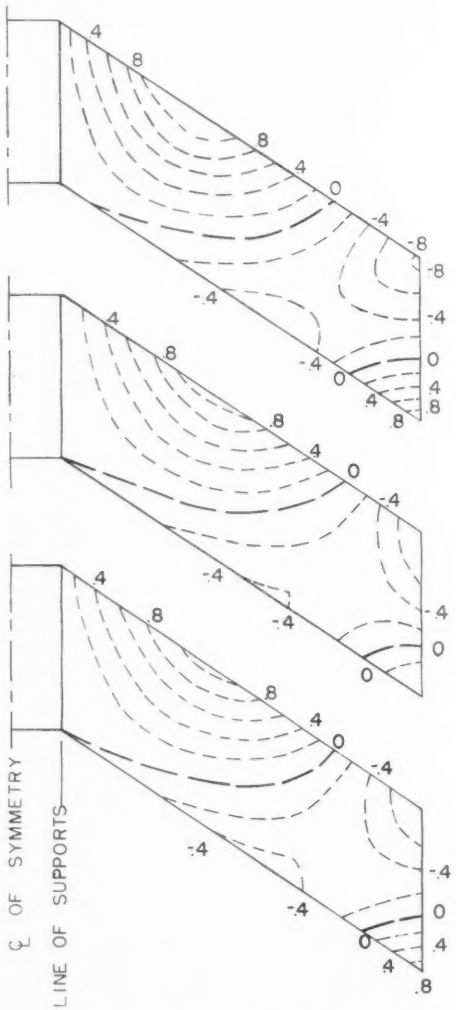


Fig. 5a. Untapered wing mode contours, fourth mode.
(*Top to bottom:* Experimental shape—frequency 75.71 cps; theoretical shape—28-node analysis, frequency 78.14 cps; theoretical shape—133-node analysis, frequency 74.89 cps.)

are located only at the numbered intersections in Fig. 6 and symmetrically about the wing spanwise centerline.

Assumptions for Analysis

A single analysis was performed based on a network of nodes at the intersections of all spars and ribs and at the spar intersections with the wing centerline. Since the panels are curved and do not lie in a plane parallel to the horizontal plane of symmetry, a transformation of coordinates was applied to the skin stiffness matrix given in reference 1. In addition, since the moment of inertia of the spars varies along their span, the spar stiffness matrices had to be modified to consider this effect.

Again the bending slope at the wing centerline was fixed at zero. In addition, the vertical displacement and chordwise bending slopes were set to zero along the support line. The dead weight of the structure was calculated, lumped at the 9 outboard node points

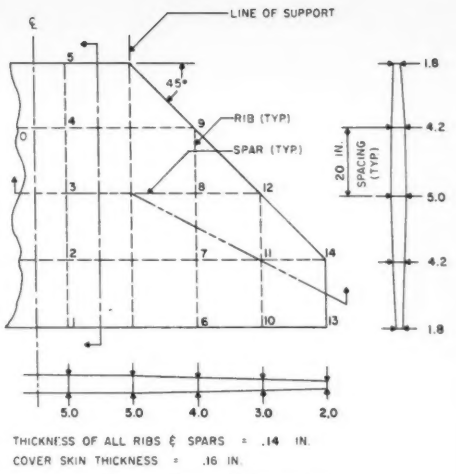


Fig. 6. Tapered wing geometry.

shown in Fig. 6 (to provide comparable mass lumping to the analog analysis), and the modes calculated. The influence coefficient matrix is given in Table 6, and the first four mode shapes and frequencies are shown in Fig. 7.

Static and Dynamic Analog Analysis

This wing has been analyzed by Benscoter and MacNeal[3] on a passive network analog computer. In addition, Zender[4] has made static tests on a plastic model with which the results of reference 3 compare favorably. Sample results for deflections are given in Table 7. Comparable stiffness and analog results are repeated for convenience. Since only plotted results appear in reference 4, only two significant figures are listed.

There is an inadequate amount of deflection data available in reference 4 to provide a satisfactory statistical comparison between analytical and test influence

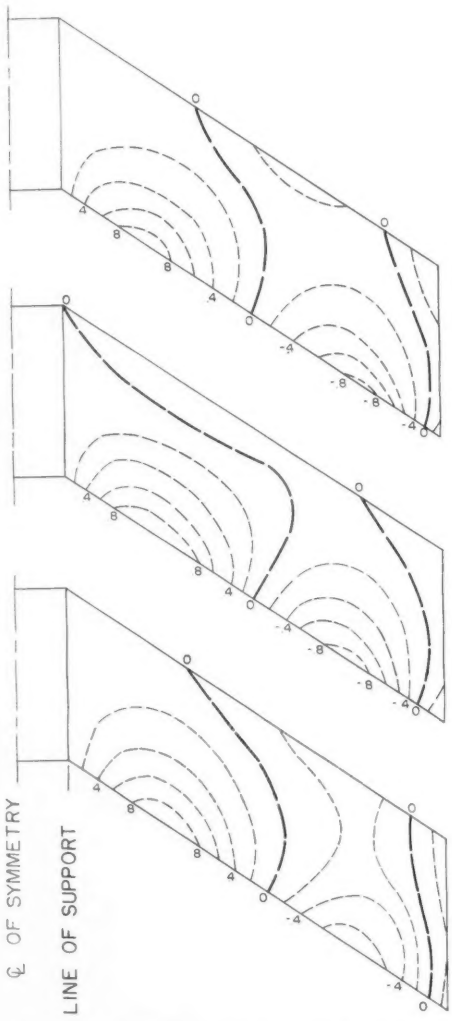


Fig. 5b. Untapered wing mode contours, fifth mode. (*Top to bottom:* Experimental shape—frequency 113.9 cps; theoretical shape—28-node analysis, frequency 124.3 cps; theoretical shape—133-node analysis, frequency 110.1 cps.)

Table 4. Differences Between Analytical and Test Influence Coefficients

Statistical Criterion	Comparison by %, 28-Node Sol'n With Exp.	Comparison by %, 133-Node Sol'n With Exp.
Average	−12.9	−3.75
Median	−12.0	−3.50
Mode	−16.0	−2.50
Range	19.9	10.5
Standard deviation	±3.47	±2.18

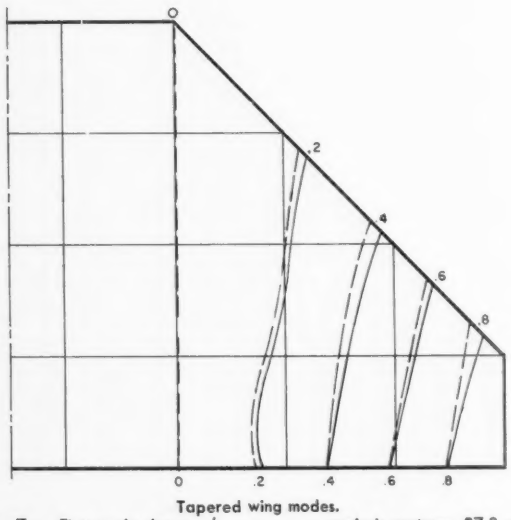
Table 5. Comparative Summary of Resonant Frequencies

Mode	Exp., cps	Theory, 28 Nodes, cps	Theory, 133 Nodes, cps	28/Exp.	133/Exp.
1	7.468	7.841	7.564	1.050	1.013
2	27.59	27.66	27.09	1.003	0.982
3	45.26	48.17	45.26	1.064	1.000
4	75.71	78.14	74.89	1.032	0.989
5	113.9	124.3	110.1	1.091	0.967

Table 6. Tapered Delta Wing—Analytical Influence Coefficient Matrix

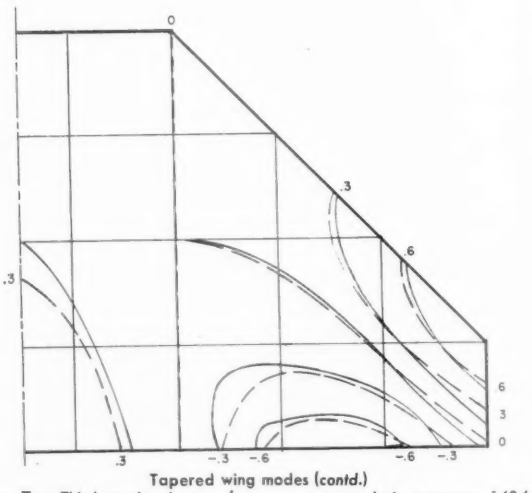
Deflection Points														Load Points
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
0.0361	0.0151	0.0088	0.0078	0.0060	−0.0188	−0.0143	−0.0113	−0.0094	−0.0307	−0.0273	−0.0240	−0.0425	−0.0401	1
	0.0149	0.0103	0.0089	0.0066	−0.0128	−0.0115	−0.0102	−0.0094	−0.0237	−0.0223	−0.0211	−0.0338	−0.0332	2
		0.0138	0.0126	0.0090	−0.0102	−0.0103	−0.0106	−0.0110	−0.0205	−0.0207	−0.0212	−0.0303	−0.0312	3
			0.0196	0.0170	−0.0097	−0.0105	−0.0116	−0.0139	−0.0203	−0.0214	−0.0232	−0.0306	−0.0325	4
				0.0373	−0.0077	−0.0089	−0.0105	−0.0145	−0.0167	−0.0184	−0.0210	−0.0256	−0.0281	5
					0.0428	0.0238	0.0146	0.0103	0.0651	0.0466	0.0326	0.0810	0.0673	6
						0.0239	0.0176	0.0131	0.0477	0.0438	0.0382	0.0683	0.0650	7
							0.0212	0.0175	0.0321	0.0355	0.0391	0.0496	0.0540	8
								0.0274	0.0225	0.0274	0.0348	0.0354	0.0420	9
		Symmetric							0.1532	0.1070	0.0748	0.2146	0.1720	10
										0.1031	0.0861	0.1666	0.1618	11
											0.0997	0.1200	0.1380	12
												0.3906	0.2993	13
													0.3094	14

Deflections in in./1,000 lbs., 24-node solution.



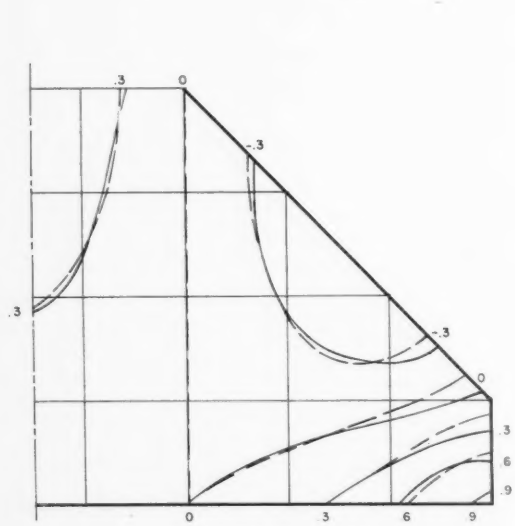
Tapered wing modes.

Fig. 7a. First mode shape. (– – – – – – analysis contours, 37.8 cps; ———— analog contours, 39.4 cps.)



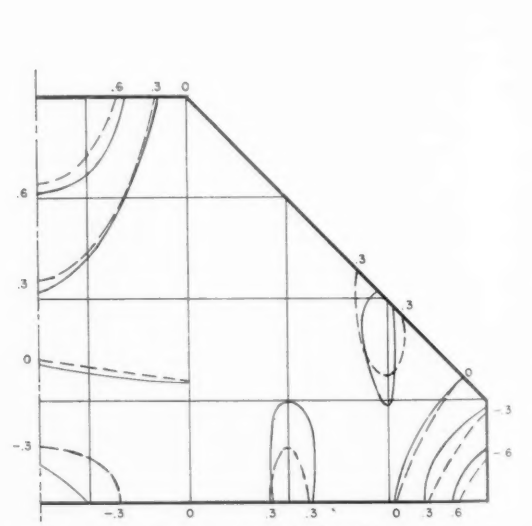
Tapered wing modes (*contd.*)

Fig. 7c. Third mode shape. (– – – – – – analysis contours, 148.6 cps; ———— analog contours, 137.2 cps.)



Tapered wing modes (*contd.*)

Fig. 7b. Second mode shape. (– – – – – – analysis contours, 110.3 cps; ———— analog contours, 112.7 cps.)



Tapered wing modes (*contd.*)

Fig. 7d. Fourth mode shape. (– – – – – analysis contours, 171.9 cps; ———— analog contours, 154.8 cps.)

Table 7. Comparison of Plastic Wing Test Deflections

One Kip Load at Node 13				One Kip Load at Node 14		
Test Defl.	Analysis Defl.	Analog Defl.	Sta.	Test Defl.	Analysis Defl.	Analog Defl.
0.08	0.08	0.08	6	0.07	0.07	0.06
0.07	0.07	0.06	7	0.07	0.07	0.06
0.05	0.05	0.04	8	0.05	0.05	0.05
0.03	0.04	0.03	9	0.04	0.04	0.04
0.22	0.21	0.21	10	0.15	0.17	0.16
0.16	0.17	0.16	11	0.15	0.16	0.15
0.12	0.12	0.11	12	0.13	0.14	0.13
0.39	0.39	0.40	13	0.28	0.30	0.29
0.28	0.30	0.29	14	0.29	0.31	0.29

data. In addition, no dynamic tests of the model were performed. Since the analog results do not suffer these limitations, the comparison in this report will be made with the analog results.

The influence coefficients obtained using the analog are shown in Table 8. Since no mass matrix was given in references 3 or 4, using the same mass matrix as used in the stiffness analysis, new modes were obtained for this wing. These modes agree fairly well with those in reference 3 and provide a fair basis for comparison of the analyses. The analog modes are shown with the analytical modes in Fig. 7.

Comparison of Stiffness and Analog Analyses

A statistical comparison of the deflection influence coefficients obtained from the two analyses is given in Table 9. All the influence coefficients are compared in the second column. Since displacements along the wing centerline are small, percentage errors in this region are large and probably do not provide a fair basis of comparison since both the analog and stiffness displacements may involve large percentage errors in comparison with the prototype. Therefore, in the second column of Table 9, the statistical comparison of influence coefficients for these points is omitted.

A comparison of the resonant frequencies is given in Table 10. The reader can make a comparison between the mode shapes of the two analyses by referring to Fig. 7. Since the fifth root for the analog solution was negative, only roots one through four are given.

Conclusions

The results of these stiffness method analyses demonstrate excellent accuracy in comparison with experimental and analog evaluations of structural behavior. The practical considerations involved in formulating mathematical models for wings of complex geometry and structural configuration do not compromise the accuracy. In the case of the first wing and fine nodal breakdown, analytical predictions of influence coefficients and mode shapes and frequencies compared to test data with considerably less error than is usually present in the experimental data itself. For the tapered wing, the results compared favorably with the analog solution (and with test) within the limits of accuracy of the analog solution. Very good results were obtained in both analyses with coarse networks.

(*Continued on page 45*)

Table 9. Differences Between Analog and Analysis Influence Coefficients

Statistical Criterion	All Data Comparison by %, Stiffness/Analog	Data for Points Outbd. of Support Line Comparison by %, Stiffness/Analog
Average	−18.3	−6.72
Median	−15.0	−8.0
Mode	−12.5	−12.5
Range	69.0	34.0
Standard deviation	±15.1	±6.67

Table 10. Comparative Summary of Resonant Frequencies

Mode	Theory, 24 Nodes, cps	Analog, cps	Stiffness/Analog
1	37.8	39.4	0.959
2	110.3	112.7	0.979
3	148.6	137.2	1.083
4	171.9	154.8	1.110

Table 8. Tapered Delta Wing—Analog Influence Coefficient Matrix

Deflection Points														Load Points
1	2	3	4	5	6	7	8	9	10	11	12	13	14	
0.0450	0.0160	0.0076	0.0046	0.0036	−0.0134	−0.0105	−0.0082	−0.0065	−0.0235	−0.0204	−0.0175	−0.0333	−0.0305	1
	0.0169	0.0085	0.0054	0.0045	−0.0093	−0.0085	−0.0072	−0.0061	−0.0178	−0.0165	−0.0151	−0.0262	−0.0248	2
		0.0131	0.0085	0.0076	−0.0068	−0.0069	−0.0070	−0.0069	−0.0140	−0.0140	−0.0142	−0.0212	−0.0211	3
			0.0171	0.0162	−0.0054	−0.0061	−0.0069	−0.0085	−0.0116	−0.0125	−0.0139	−0.0176	−0.0188	4
				0.0456	−0.0053	−0.0063	−0.0078	−0.0114	−0.0116	−0.0131	−0.0152	−0.0176	−0.0194	5
					0.0511	0.0240	0.0139	0.0088	0.0654	0.0436	0.0288	0.0795	0.0596	6
						0.0251	0.0162	0.0116	0.0440	0.0407	0.0327	0.0614	0.0574	7
							0.0214	0.0158	0.0287	0.0316	0.0346	0.0443	0.0478	8
								0.0259	0.0194	0.0240	0.0312	0.0301	0.0354	9
									0.1585	0.1031	0.0700	0.2098	0.1574	10
										0.1000	0.0784	0.1571	0.1498	11
		Symmetric									0.0912	0.1142	0.1268	12
												0.3983	0.2863	13
													0.2901	14

Deflections in in./1,000 lbs.

Heat Protection by Ablation

The recent extensive use of ablation materials has raised basic questions concerning what properties to look for in ablation systems for accomplishing different tasks.
Some practical answers are provided for different popular materials and applications.

Robert M. Wood, MIAS, and Ronald J. Tagliani, MIAS

Douglas Aircraft Company, Inc.

A MODEL consisting of a metal load-carrying structure covered with a protective coating is discussed and chosen as an efficient method of dissipating the severe heating encountered by hypersonic vehicles in transient flight. The concepts of heat and temperature of ablation are used together with other coating material properties for describing the effectiveness of different protective coatings in different thermal environments. The assumption of an equivalent square wave heat-time input for any actual environment is discussed and justified for radically different environmental situations, including ICBM, Mars entry, anti-ICBM, manned entry, and nozzle applications. Using the square wave heat input assumption, the unit coating weight required is presented as a function of intensity and duration of heating for several different protective coatings.

Three domains of heating are categorized: (1) almost complete ablation, wherein the most important material property is heat absorbed per pound of material lost; (2) partial ablation, wherein density and conductivity are as important as ablation properties; and (3) no ablation, wherein ordinary thermal properties are all important. The results are summarized by the graphical presentation of the relative coating weights required with a number of popular protection materials for a number of different environmental situations, thereby emphasizing the need for different thermal properties with various environments.

Objectives, Approach, and Assumptions

Heat Protection Systems

The purpose of this paper is to discuss the desirable thermal and ablation properties of materials used for

Symbols

A	=	$\rho k t_F / w^2 c$
B	=	$\rho k t_F / (\rho c b)_m w$
C	=	$\dot{q} t_F / w Q_D$
C_H	=	Stanton number with mass transfer
C_{H_0}	=	Stanton number without mass transfer
D	=	$[(T_A - T_0)\rho k t_F] / w^2 Q_D$
Q_A	=	heat of ablation
Q_D	=	heat of decomposition
Q^*	=	effective heat of ablation
T	=	temperature
$\bar{T}$	=	$(T - T_0)/(T_A - T_0)$
$W/C_D A$	=	weight to drag ratio
a	=	coating thickness
b	=	metal thickness
c	=	specific heat
h_c	=	convective heat-transfer coefficient
k	=	thermal conductivity
$\dot{q}$	=	heat flux rate
s	=	thickness ablated
t	=	time
w	=	unit coating weight
x	=	distance from coating initial outer surface
δ	=	penetration distances of temperature wave
ϵ	=	emissivity
ρ	=	material density
σ	=	s/a
τ	=	t/t_F
θ	=	entry angle
ξ	=	$(a - x)/(a - s)$

Subscripts

A	=	ablation
AVG	=	average
B	=	boundary-layer recovery conditions
F	=	final conditions
0	=	initial conditions
W	=	wall conditions
m	=	metal properties

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protecting load-carrying structures from excessive temperatures, and their interrelationship with the environment to which such protective coatings are subjected. It has previously been shown how the structural requirements can be superimposed upon the thermal results and a minimum weight combined structure evolved for an AICBM environment.[1] The emphasis herein is on how different environments will point towards different desirable materials for thermal protection.

There are several methods of dissipating the heat that is generated by high-velocity flight or propulsion systems:

(1) Solid and Liquid Heat Sinks—A large mass is used to absorb all the heat sensibly and to still maintain the structure at an acceptable temperature.

(2) Transpiration Cooling—A gas is ejected through a porous skin into the boundary layer, thereby thickening and cooling the boundary layer so that the heat flux rate is reduced to an acceptable value.

(3) Radiation Cooling—A very thin outer shell (usually metal) is allowed to reach a very high temperature (>2000°F.) thereby rejecting a large quantity of heat by radiation and maintaining an insulated substructure cool enough to withstand the required loading.

(4) Protective Coating—An ablative* or nonablative coating is used to keep the basic load-carrying structure to an acceptable temperature.

Each of the different methods appears most efficient for different thermal environments. Theoretically, however, it can be shown that the protective coating method could be the most efficient for nearly all environments, for if the thermal conductivity of the protective coating is made to approach zero, and the temperature of ablation is sufficiently large, the weight of coating required will also approach zero. Even though this is a hypothetical example, it is felt that materials development is proceeding at such a rapid pace that protective coatings will soon be the most efficient method of dissipating heat, from a weight standpoint, for all but steady-state thermal environments. An exception is the case where the heating is so small that the basic load-carrying structure can survive with no coating.

As a result of these considerations this presentation will deal only with the protective coating method of heat dissipation. It is assumed in all cases that a metal load-carrying structure must be protected to a given maximum temperature (see Fig. 1).

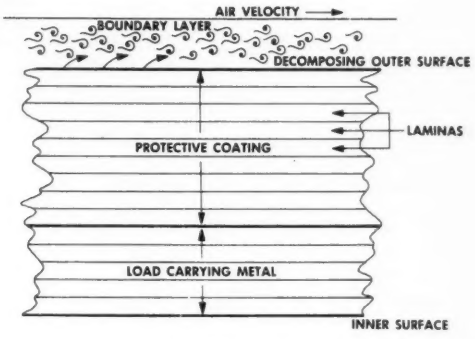

Fig. 1. Analytical model.

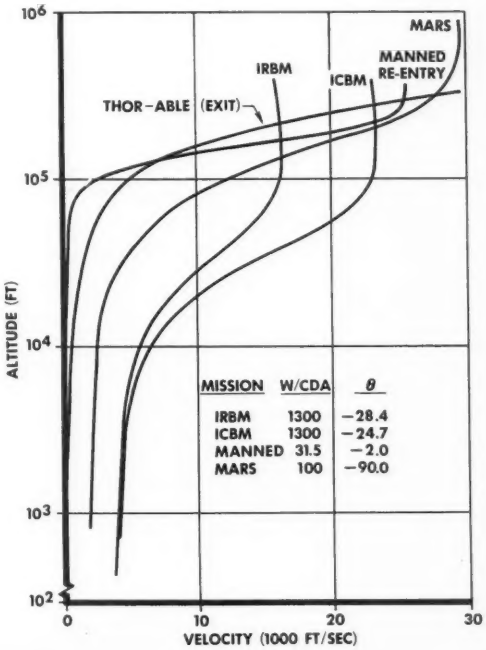

Fig. 2. Trajectories.

* Ablation is the removal of a material at its surface by a moving gas as a result of heat and shear.

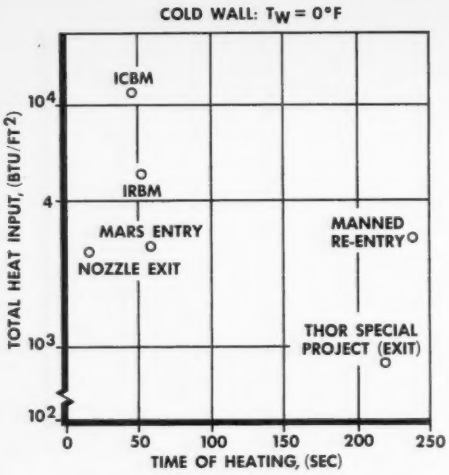

Fig. 3. Total heat input and time of heating.

Environments

Largely different environmental situations are suggested by Fig. 2, which gives the altitude-velocity relationships for an IRBM, ICBM, Mars entry, manned re-entry to earth, and a Thor Special Project exit. The lower and farther to the right such curves are, the more severe the heating because at a given altitude the speed is higher. Extremely short or long times will change this conclusion. An AICBM trajectory has been considered, but security restrictions prevent giving the corresponding plot. In order to illustrate the differences in heating and time of heating for each of the different trajectories shown in Fig. 2, a typical body geometry has been chosen for all heating calculations. The point of analysis is one foot aft of the stagnation point of a blunt 10° cone, assuming that the flow goes through a normal shock. The heating on that type of surface is felt to be representative of the areas where most of the coating weight will be concentrated for many missile or space vehicles. The differences in time of heating as well as total heat input (to a 0°F. surface) for the trajectories of Fig. 2 are shown in Fig. 3. The time of heating is defined as the time between the two values of heat flux equal to 5 per cent of the maximum. This will be illustrated below.

Model and Definitions

We return now to the analytical model and assumptions, having touched on the different environments which will be considered for the purpose of this analysis. The analytical model is shown in Fig. 1. The model consists of a basic metal load-carrying structure covered with a protective coating which may be either ablative or nonablative. The outer surface of the protective coating is subjected to a net heat flux rate $\dot{q}$ which is assumed to be constant with time for this part of the analysis. The assumption of a constant heat flux rate will be justified below by showing how these results can be utilized for many cases in which a variable heat flux rate exists. In addition to the environmental variables of heat flux rate and time, the material property variables involved are as follows:

(1) ρ	(5) Q_D
(2) k	(6) $(\rho cb)_m$
(3) c	(7) T_F
(4) T_A	(8) a

Some of the terms used in the discussion of ablative coatings will now be defined since they are not universally accepted. For the purposes of this study the heat of decomposition Q_D is defined as the amount of heat absorbed due to chemical reactions or phase change which take place at the ablation temperature T_A. It is assumed that the coating material decomposes at a constant temperature T_A in changing from the solid state to the vapor state. The term heat of ablation as used herein is defined as the heat of decomposition plus the sensible heat. Another term which is used quite frequently in the literature is the effective heat of ablation or Q^*. This term is primarily used in the analysis of experimental ablation data and all the effects of decomposition, sensible heat, mass transfer, radiation, and shear removal can be lumped into one parameter. That term will not be used in this analysis since the mass transfer is accounted for by a reduction in the heat flux rather than by an increase in the heat of ablation, and the other effects are taken into account separately.

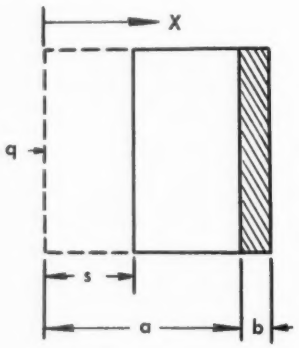

Fig. 4. Physical nomenclature.

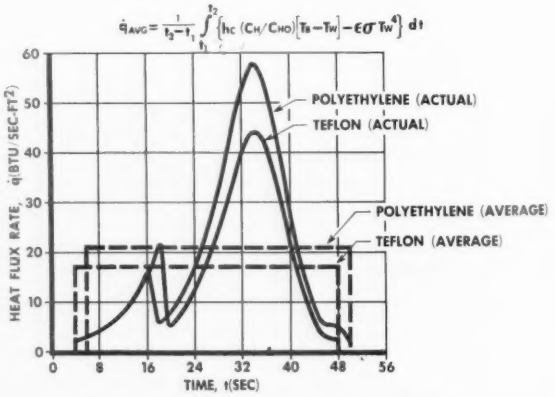

Fig. 5. Heat flux rate histories for entry into Mars.

Table 1. Comparison of Coating Weights for Actual and Square Wave Heat Inputs

Application	Phenolic Nylon	Quartz	Teflon High Density	Teflon Low Density	Polyethylene
ICBM					
W sq. wave (lb./ft.²)	2.73	1.40	4.60	4.50	3.60
W actual (lb./ft.²)	2.74	1.50	4.50	4.45	3.55
% Error	−0.4	−6.7	+2.2	+1.1	+1.4
Nozzle exit plane					
W sq. wave	0.65	0.73	1.32	1.42	1.01
W actual	0.64	0.80	1.28	1.34	1.00
% Error	+1.4	−9.2	+3.1	+6.0	+1.0
Manned re-entry					
W sq. wave	1.58	2.95	2.60	0.70	1.24
W actual	1.67	3.95	2.72	0.75	1.15
% Error	−5.4	−25.3	−4.4	+7.1	+7.8
Mars entry					
W sq. wave	0.60	1.22	1.05	0.58	0.59
W actual	0.62	1.59	1.02	0.58	0.59
% Error	−3.2	−23.2	+1.9	0	0
AICBM					
W sq. wave	1.10	1.64	2.05	1.90	1.58
W actual	1.09	1.82	2.14	1.85	1.61
% Error	+0.9	−9.9	−4.2	+2.7	−1.9

Equations and Boundary Conditions

The governing equations and boundary conditions for the analytical model are given here and in Fig. 4.

$$(\partial T/\partial t) - (k/\rho c)(\partial^2 T/\partial x^2) = 0 \quad (1)$$

$$T(x, 0) = T_0 \quad (2)$$

$$(\partial T/\partial t)\big|_{x=a} + \{[k/(\rho c b)_m](\partial T/\partial x)\}\big|_{x=a} = 0 \quad (3)$$

$$\dot{q} - \rho Q_D(ds/dt) + k(\partial T/\partial x)\big|_{x=s} = 0 \quad (4)$$

$$T(s, t) = T_A \text{ (ablative coating)}$$

$$T(s, t) < T_A \text{ then } ds/dt = 0 \text{ (nonablative coating)} \quad (5)$$

$$T(a, t_F) = T_F \quad (6)$$

Eq. (1) is merely the Fourier conduction equation which describes the heat flow in the coating. The first boundary condition, Eq. (2), specifies that at time zero, the entire coating is at an initial temperature T_0. The second boundary condition, Eq. (3), is applied at the interface between the coating and metal and indicates that all the heat which flows from the coating goes into raising the temperature of the metal. The third boundary condition, Eq. (4), is applied at the outer surface of the coating and states that the heat flux that is applied is absorbed by decomposition of the material and conduction through the material. The final boundary condition, Eq. (5), merely indicates that if the surface temperature is equal to T_A, then decomposition will occur, and if it is less than T_A, decomposition will not occur. A requirement as specified earlier is that the metal temperature reach a specified limit T_F at the final time t_F, Eq. (6). Eqs. (1)–(6) can be transposed to a nondimensional form, as shown in Eqs. (7)–(12).

$$\frac{\partial \bar{T}}{\partial \tau} + \frac{\xi}{1-\sigma}\frac{d\sigma}{d\tau}\frac{\partial \bar{T}}{\partial \xi} - \frac{A}{(1-\sigma)^2} - \frac{\partial^2 \bar{T}}{\partial \xi^2} = 0 \quad (7)$$

$$\bar{T}(\xi, 0) = 0 \quad (8)$$

$$(\partial \bar{T}/\partial \tau)\big|_{\xi=0} - \{[B/(1-\sigma)](\partial \bar{T}/\partial \xi)\}\big|_{\xi=0} = 0 \quad (9)$$

$$(d\sigma/d\tau) - C + \{[D/(1-\sigma)](\partial \bar{T}/\partial \xi)\}\big|_{\xi=1} = 0 \quad (10)$$

$$\bar{T}(1, \tau) = 1 \text{ (ablative coating)}$$

$$\bar{T}(1, \tau) < 1 \quad \text{then } d\sigma/d\tau = 0 \text{ (nonablative coating)} \quad (11)$$

$$\bar{T}(0, 1) = \bar{T}_F \quad (12)$$

The dimensionless parameter ξ is used to combine the time-space variables so that at the outer surface of the coating $\xi = 1$ and at the inner surface $\xi = 0$ regardless of the amount of material ablated. The remaining transformations are fairly straightforward and are defined in the list of symbols. Four dimensionless parameters—A, B, C, and D—appear throughout the equations and contain all the environmental and material property variables; these parameters are defined in the list of symbols. The most interesting point to note about these parameters is the fact that, once the coating thickness a is replaced by the unit coating weight ρa, then the density ρ and thermal conductivity k always appear together as a product. This fact eliminates one material property variable, and applies to any transient or steady-state heat flow in an insulator. In addition, it is noted that the time of heating t_F only appears with either the heat flux rate $\dot{q}$ or with ρk. This is an important point which will be utilized later.

Square Wave Heat Pulse

It has been mentioned that a square wave heat pulse is used. The usefulness of this concept will now be presented. Fig. 5 shows the heat flux rate time histories for the Mars entry trajectory for two materials: Teflon and polyethylene. The curves were computed by the Douglas Aircraft Company missile heating programs with an IBM 704 (General Missile Heating Programs J02, J18, J22) which determine conditions outside the boundary layer at each time instant, computes heat-transfer rates,[2,3] solves the heat flow in the materials, allows for decomposition, and corrects the heat input depending on the mass transfer.[4] The dashed curves show the square wave heat pulses which are roughly equivalent. The square wave starts and ends when the heat flux is 5 per cent of the maximum, and the total

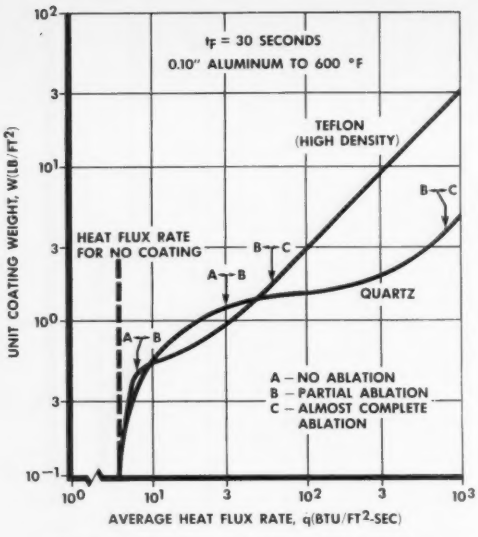

Fig. 6. Unit coating weight for typical materials.

areas under the real curve and the equivalent curve between the times are equal. The actual equation which is used for computing the magnitude of the square wave heat pulse is also shown in Fig. 5. As can be seen, the square wave heat pulse is actually a net average heat flux rate which has been corrected for surface temperature and mass transfer.

Table 1 shows a comparison of coating weights required to keep 0.10 in. of aluminum to 600°F., for both the square wave assumption and the actual case, with the per cent errors. Only two weights differ by more than 10 per cent. The reason for the large error in these two weights is due to the long flight time at which a negative heat flux rate exists. In other words, the square wave assumption cannot account for long periods of time at negative heat flux rates where heat is being conducted through to the metal, and consequently requiring more insulation than would be predicted by the square wave assumption. Since drastically different environments and materials have been used here it would seem that this agreement would encourage the use of the simple square wave concept, at least for order of magnitude purposes.

Assumed Material Properties

The material properties which are used for several popular protective coating materials are given in Table 2. The first column, ablation temperature, ranges from 775°F. for polyethylene to 4,000°F. for quartz. The temperature of ablation is a function of the rate of decomposition and so would vary with external heat flux rate. Since in many cases the viscous forces are very small, materials having ablation temperatures occurring above the published material melting points are usable. The heats of decomposition and ablation differ only by $c(T_A - T_0)$, and have been shown to be in agreement with chemical pyrolysis data for Teflon.[6] The last column shows the ρk product; the lower the ρk, as long as all the other properties do not change, the lighter the coating. Although, as indicated, the exact values of these properties may not be valid for all situations,[7] the important point is that they represent a broad spectrum of materials.

Implications and Applications

Regions of Ablation

Having considered general definitions and the use of a square wave heat input, let us now look at some of the coating weights required to keep 0.10 in. of aluminum to 600°F. Fig. 6 shows this weight (for 30-sec. heating) as a function of the average heat flux rate and for two materials, Teflon and quartz. At the left-hand side, there is a heat flux below which the aluminum temperature never rises above 600°F., and so no coating is required. Three distinct domains or regions can be observed. The first is the region of no ablation, the second is partial ablation and the third is complete ablation. As can be seen, these regions are a function of the material property variables and will shift accordingly as the material properties are changed.

Almost complete ablation occurs when the heat flux rate is sufficiently high for a given material so that the coating ablates at a rate almost equal to the rate at which the temperature wave is conducted through the material. When this situation exists, nearly all of the protective coating is ablated before the metal temperature has risen appreciably. The protective coating weight required can be approximated quite accurately by a simple heat balance for the case of almost complete ablation.

$$wQ_A = \dot{q}t - (\rho c b_m)(T_F - T_0) \qquad (13)$$

Eq. (13) is exact for the case of complete ablation. As implied previously the boundaries for the region of almost complete ablation are a function of the material property variables in addition to the heat flux rate. From the exact solution for the temperature distribution

Table 2. Approximate Physical Properties of Various Protective Coatings*

	T_A(°F.)	Q_D(B.t.u./lb.)	Q_A(B.t.u./lb.)	c(B.t.u./lb.°F.)	ρk(B.t.u.-lb.)/(hour-ft.⁴-°F.)
Teflon (high density)	1,100	690	940	0.25	19
Fiberglas (phenolic)	3,000	750	1,910	0.40	25.5
Nylon (phenolic)	1,400	1,500	1,950	0.35	8.2
Polyethylene	775	1,090	1,460	0.55	11.8
Teflon (low density)	1,100	690	940	0.25	2.0
Quartz	4,000	5,000	6,100	0.28	22

* These properties were derived from unclassified literature and are only approximate in the sense that they are not necessarily valid for all ranges of temperature, pressure, and heat flux.

through an ablating (steady state) infinite wall,[8] it is possible to define the heat flux rate at which almost complete ablation would occur for given material properties, Eq. (14).

$$\dot{q}\sqrt{\frac{t_F}{\rho k}} = Q_A\sqrt{\frac{-1}{c\delta/a}\ln\frac{T_\delta - T_0}{T_A - T_0}} \qquad (14)$$

If the ratio of the thickness penetrated by the temperature wave to the total thickness of coating, δ/a, is very small, then the coating will almost completely ablate before the metal temperature can rise to its final required value T_F. Therefore, by choosing a small value for δ/a and a T_δ near the initial temperature T_0, Eq. (14) can be used to determine the heat flux rate at which almost complete ablation will exist for given coating properties and time of heating. For that domain of heating, the weight of coating required can be quickly determined from Eq. (13). In the region of almost complete ablation, the most important material property is the heat of ablation; the value of the ρk parameter is not important at all, except to determine whether one is in this region. Much of the effort to date has been directed towards finding materials suitable for the region of almost complete ablation.[9]

The next region considered is that of no ablation. This occurs when the final metal temperature is reached before the outer surface reaches the ablation temperature. This situation would occur for materials with high temperatures of ablation subjected to low heat flux rates. The coating weight required to maintain 0.10 in. of aluminum to 600°F. is shown in Fig. 7 for the region of no ablation and arbitrary material properties. The time parameter t_F is incorporated with ρk and $\dot{q}$ as described earlier. This makes Fig. 7 fairly general in that it is now restricted only to a given metal heat capacity and a coating specific heat of 0.30 B.t.u./lb.°F. Since the coating weights are usually insensitive to specific heat over a practical range, this value is typical but not crucial. The solid lines in Fig. 7 represent the coating weight required for different values of $\rho k t_F$, and the dashed lines represent the maximum surface temperature achieved for a given $\rho k t_F$ and $\dot{q}t_F$. These results were obtained by a digital solution of the diffusion equation with a square wave heat pulse. For

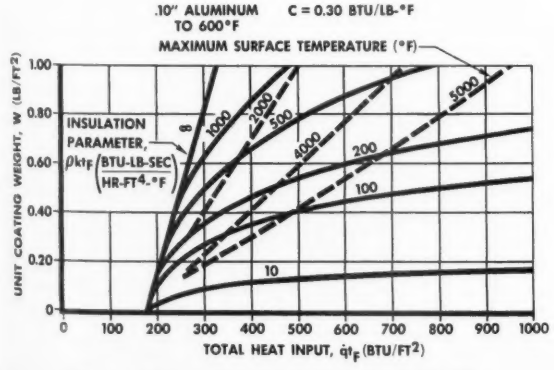

Fig. 7. Coating weight for the region of no ablation.

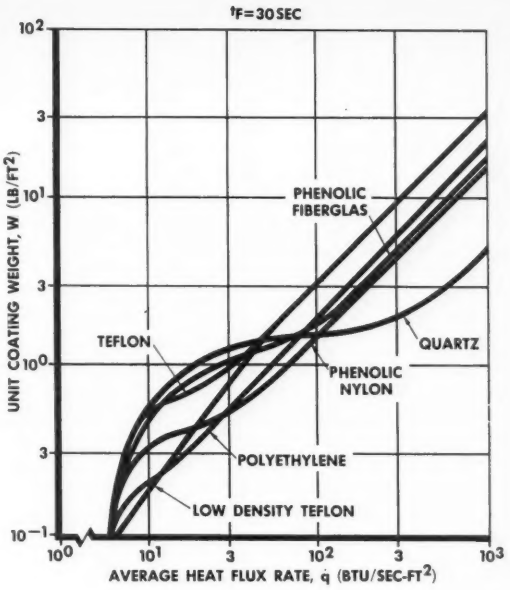

Fig. 8. Coating weights.

a given heat flux rate, time and ρk, it can be determined from Fig. 7 if the maximum surface temperature is greater than or less than the ablation temperature of the material under consideration. If the maximum surface temperature is less than the ablation temperature, then there is no ablation and the coating weight can be determined directly from Fig. 7. If the maximum surface temperature is greater than the ablation temperature, then ablation will occur and Eq. (14) must be used to determine if one is in the region of almost complete ablation or partial ablation. It is clear from Fig. 7 that for the region of no ablation it is desirable to have a high temperature of ablation combined with a low value of ρk.

The region of partial ablation is defined by elimination and lies between the regions of almost complete ablation and no ablation. None of the material property variables can be eliminated in this region because no ablation occurs part of the time and the material ablates the remainder of the time. It is therefore very difficult to present generalized results of unit coating weight variations. Thus, this discussion will be included in the following section, where coating weight variations in the region of partial ablation will be considered for specific present-day materials. It must be emphasized that in the region of partial ablation both the ρk parameter and the ablation properties (T_A and Q_A) of a material are equally important. In general it is always desirable to have a low value of the ρk parameter in the region of partial ablation.

Variation of Protective Coating Weights With Heat Flux and Time

Fig. 8 presents the coating weights for specific materials for 30-sec. heating as a function of heat flux rate. At low heat fluxes, low density Teflon and polyethylene

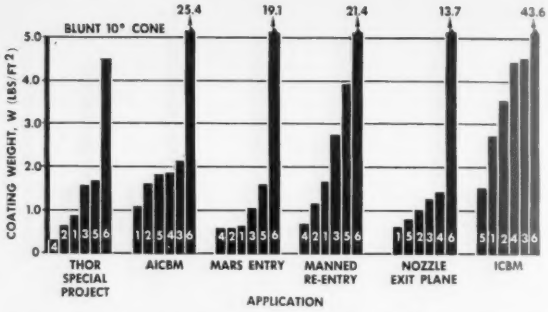

Fig. 9. Comparison of protective coating materials: (1) phenolic nylon, (2) polyethylene, (3) Teflon (high density), (4) Teflon (low density), (5) quartz, and (6) bare aluminum.

are lightest in weight because of the low ρk in the case of the Teflon and because of the low temperature of ablation in the case of the polyethylene. The worst material is quartz. At intermediate heat flux rates, such as in the exit of a nozzle, polyethylene, phenolic nylon, phenolic Fiberglas, and quartz become competitive. the first three are entering the region of almost complete ablation, whereas the quartz is ablating partially, and the high heat of ablation is starting to compensate for the high ρk. At higher heat flux rates (such as nozzle throats) quartz is the uncontested winner in the region of complete ablation. Another interesting point to note on Fig. 8 is the difference between the low and high density Teflon curves. The only difference in the properties of these materials is the ρk, which for the low density Teflon is approximately a factor of 10 lower than the high density Teflon. This difference results in a significant difference in weight at low values of $\dot{q}$, but for heat flux rates in excess of about 60 the required weights of the two materials are identical, thereby again showing that the ρk product is unimportant in the region of almost complete ablation, but very important in the regions of partial ablation and no ablation. The trends shown in Fig. 8 are the same for longer times of heating but the curves are shifted up somewhat.

Variation of Protective Coating Weights With Mission

Thus, the environment dictates the material. Fig. 9 highlights this point by showing the absolute and relative ratings of five coating materials on six different missions. For a Thor Special Project application with a long-time low heat flux, low density Teflon looks best, with the low ablation temperature of polyethylene making it second. The best material for the AICBM trajectory would be phenolic nylon, with little to choose from among the other four. For the Mars entry, phenolic nylon, polyethylene, and low density Teflon look good, and for the manned re-entry low density Teflon is good because of the low ρk. Quartz is about seven times as heavy. The high heat flux rate short-time situation for the ICBM application make quartz best and the low heat of ablation materials the worst. The situation for the particular nozzle exit chosen is similar to the ICBM because of the short time of heating; however, the heat flux rates are somewhat lower. In addition to the protective coating materials, bare aluminum is also shown for each application to illustrate the need for a protective coating in order to achieve minimum weight. Approximately 1.5 lb./ft.^{2} should be added to these weights for the 0.10 in. of aluminum which is being protected, in order to get total skin weight.

Conclusions

The broad picture is summarized on Fig. 10. It should be mentioned that the average heat flux rate shown on Fig. 10 is that which was defined on Fig. 5 and is corrected for surface temperature and mass transfer. This is the reason for the variation in heat flux rates and times for the same mission and different materials on Fig. 10. For very low heat flux rates or times, no protection is required and the heat sink approach is most efficient. Ballistic manned entry nearly falls in this category. For high heat flux rates such as those existing for an IRBM or ICBM, high heat of ablation is crucial and the ρk product is not very important. This region has probably received the most attention to date in attempts to find materials which show a minimum weight of ablation. This is also reflected in many test facilities which subject materials to extremely high heat flux rates for short periods of time. The reason for this has been the extreme interest exhibited in stagnation heating where the heat flux rates are normally very high. Intermediate heat flux rates which may exist for geometries other than stagnation points and missions other than "slick" re-entry result in a critical interest in the ρk product, temperature and heat of ablation. Two examples of this are the Mars entry and nozzle exit. The inclusion of the ρk product is the important point; coatings which do not have low ρk do not provide thermal protection irrespective of their ablation properties. It would thus appear that more effort should be directed toward finding efficient materials for the intermediate heat flux region; this is not nearly as straightforward as for the high heat flux region. In view of the preceding points, it can be seen

(*Continued on page 45*)

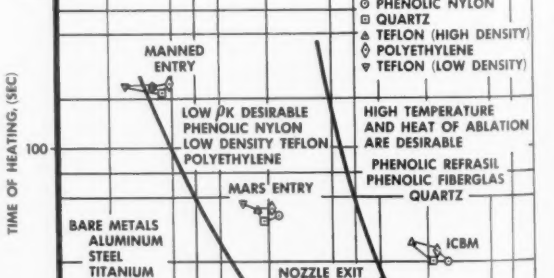

Fig. 10. Most effective protective coatings for different thermal environments.

Refractory Materials

Part II—High-Temperature Behavior

Part I, published in June, discussed the general technology of refractory materials, their stability, and their mechanical behavior at low temperatures. Part II discusses their mechanical behavior at elevated temperatures and the physical properties important in controlling thermal stresses developed in structural applications. Future trends for these materials are also suggested.

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Battelle Memorial Institute

REFRACTORY MATERIALS are being considered for structural elements in advanced airframe and propulsion structures. In last month's issue, Part I of this two-part article dealt with the compositions of refractory materials, comprising 122 materials melting above 1,800°C., and their general technological behavior, using metals as a frame of reference. The questions of stability in service and low-temperature brittleness were also covered. Part II in the current issue deals with mechanical behavior of refractory materials at elevated temperatures. This includes the thermally activated process of diffusion, creep, and recrystallization, which are important to the ability of a material to maintain structural integrity at elevated temperatures. Thermal stresses loom equally important as mechanical stresses for many of the expected applications of refractory materials. The physical properties governing thermal stress are compared. The course of future developments in this very new field is briefly outlined.

High-Temperature Mechanical Behavior

Some elevated-temperature properties of metals are influenced by thermal agitation of the atoms. These thermally activated processes include diffusion, creep, recrystallization, and melting. Dorn[17] and others have shown that elevated-temperature creep of metals occurs by a process of dislocation climb, which requires thermal

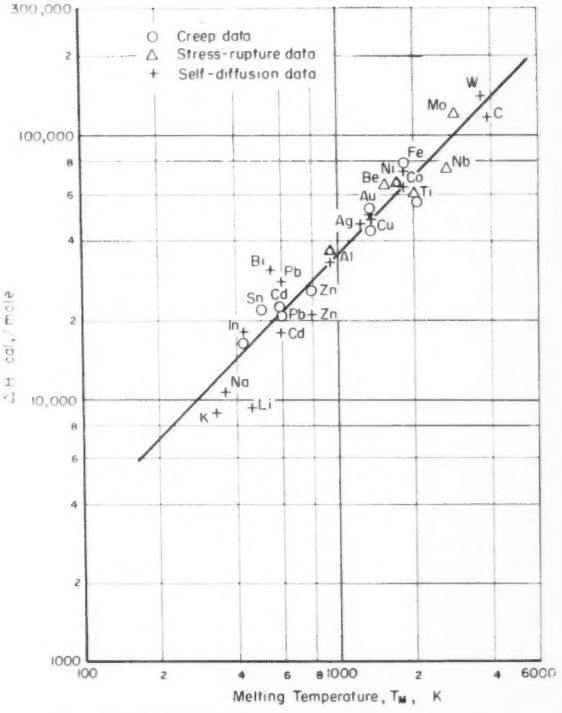

Fig. 7. Correlation of the activation energies for creep, stress-rupture, and self-diffusion with the melting temperature.[17]

activation and diffusion of atoms. The creep rate varies with temperature according to the relationship

$$\dot{\epsilon} = ke^{-(Q/RT)}$$

where $\dot{\epsilon}$ is creep rate, R the universal gas constant, T the absolute temperature, and Q the activation energy for creep. The greater the activation energy and the lower the temperature, the lower will be the creep rate, according to the exponential function. For high-temperature creep $[T > (1/2)T_m]$, the activation energy for creep and that for self-diffusion are equal and correlate well with melting point, as illustrated in Fig. 7. Thus, materials with greater melting points offer the greatest potential for development of high-temperature strength.

Recovery and recrystallization also are thermally activated processes. Strength is maintained rather well up to recovery temperatures, beyond which it drops rapidly. The grain boundaries relax under stress, and the metal recrystallizes during deformation, and the nature of the fracture changes from ductile shear to less ductile grain-boundary fracture. Below the recovery and recrystallization temperature, metals may take advantage of strengthening by work-hardening. A chart illustrating the work-hardening and recrystallization of the refractory metals is shown in Fig. 8. It is apparent that the metals with high activation energies for self-diffusion and high melting points also have high recrystallization temperatures.

It is difficult to make a valid comparison of the strengths of the refractory metals on the basis of homologous temperature T/T_m because of the potent effects

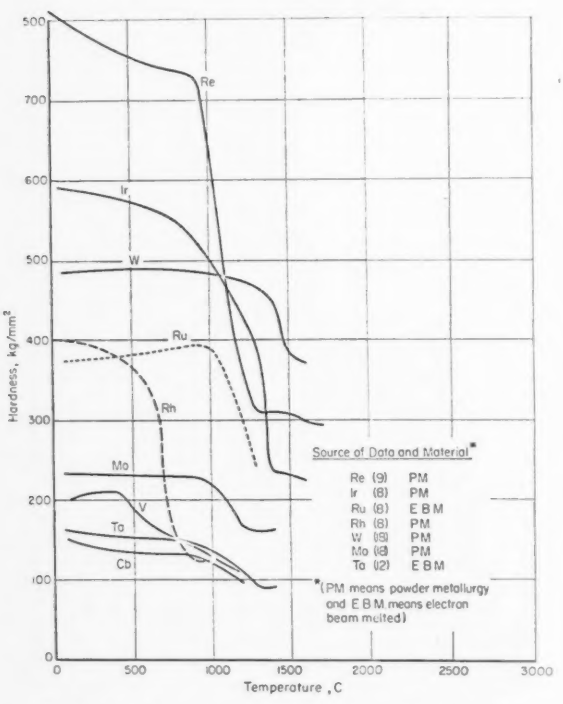

Fig. 8. Softening and recrystallization of the refractory metals. (Materials with 30 to 50 per cent cold work and heated one hour at temperature.)

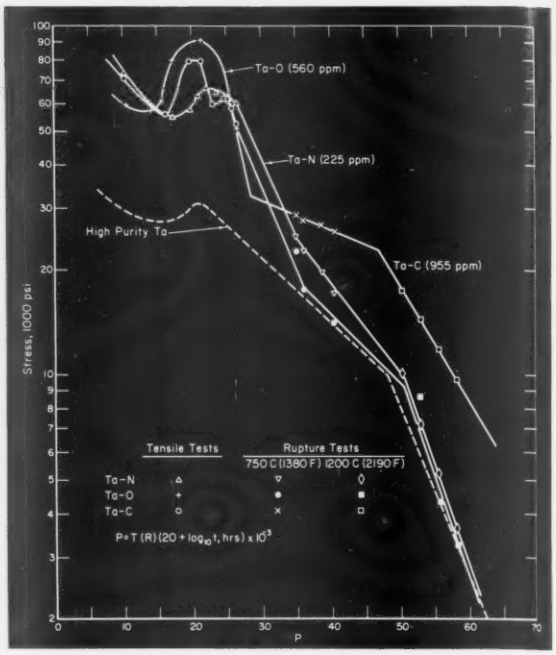

Fig. 9. Larson-Miller plot comparing rupture properties of high-purity tantalum, Ta-C, Ta-O, and Ta-N alloys.[12]

of impurities. The impurities are most influential at lower temperatures, but in some cases the effects also persist to elevated temperatures. This is particularly the case when the impurities form finely dispersed phases that inhibit creep. The effects of interstitially dissolving oxygen and nitrogen and dispersion-forming carbon on the high-temperature strength of tantalum are illustrated in Fig. 9. Indeed, fine dispersion of insoluble phases is one of the chief mechanisms for improving elevated-temperature creep. Grain size also affects elevated-temperature behavior. When the strain rate in deformation is high enough that transcrystalline slip is the primary mode of deformation, decreasing the grain size improves strength. At lower strain rates and higher temperature, when grain-boundary shear is the predominant mechanism, decreasing the grain size decreases creep strength. For maximum resistance to creep at the highest possible temperature, large grain size is definitely beneficial.

The elevated-temperature strength of refractory metals may be improved by cold work, solid-solution alloying, interstitial solution, and dispersions of insoluble compounds. Some alloys derive their elevated-temperature properties from all mechanisms, whereas for others only one or two may be operative. In the case of molybdenum, solid-solution alloying and dispersion-hardening from the interaction of carbon with reactive alloying elements are the primary mechanisms. Most molybdenum alloys are used in the hot-cold worked condition, and recrystallization is avoided because of the loss in high-temperature strength and the increased low-temperature brittleness that result. A typical high-temperature molybdenum alloy is Mo-

0.5Ti-0.07Zr, with 0.03 to 0.05 per cent carbon present for the formation of fine, submicroscopic carbide dispersions. In the case of tungsten, alloying is chiefly through insoluble-oxide dispersions, such as thorium oxide. The high-temperature strength characteristics of molybdenum and tungsten and their alloys are illustrated in Figs. 10 and 11.

Solid-solution strengthening is of considerable importance in columbium and tantalum alloys. As a result, they tend to use larger amounts of alloy content, as illustrated by the Cb-15W-5Mo-1Zr and Ta-10W alloys. In the case of the columbium alloy mentioned, interstitial carbon also is added to form a finely dispersed carbide, which contributes considerably to strength.

In commercial alloys of molybdenum and tungsten, solid solution is achieved by alloying with each other. For limited applications, substantial additions of rhenium to tungsten and molybdenum are very beneficial to elevated-temperature strength, as well as to improvement of low-temperature ductility.

It is of interest to compare the elevated-temperature strength of nonmetals with those of metals, shown in Fig. 11. The resemblance in behavior is remarkable. It is seen for the oxides that there is a change in behavior, and a rapid loss in strength occurs at 1,000° to 1,200°C. This behavior is the result of the change in fracture characteristics from transcrystalline to intercrystalline.[4] The same behavior occurs in metals in the recovery-recrystallization temperature. The loss in strength occurs at a homologous temperature of 0.6 for aluminum oxide, 0.35 for ZrC, and 0.5 for $MgAl_2O_4$. This is roughly the same homologous-temperature range where the knee in the strength curve for metals occurs. Thus, the strength potential of the nonmetals may be considered in relation to their melting point, similar to metallic materials. Structural properties are generally maintained up to about 60 per cent of the absolute melting point.

In many nonmetals, such as $MoSi_2$ and graphite, strength increases as temperature increases. This same trend is apparent in Fig. 12, where modulus of rupture in bending is plotted for various nonmetallic materials. The low strength at low temperature may be the result of excessive notch sensitivity, with premature fracture occurring before the intrinsic strength of the material is achieved. The same behavior may be noted in notched molybdenum, as shown in Fig. 13. It appears that both $MoSi_2$ and graphite reach a strength peak, beyond which strength drops—probably as a result of grain-boundary fracture.

As illustrated in Fig. 11, the elevated-temperature strengths of metals can be considerably enhanced by alloying. Strengthening through alloying also appears possible for some of the intermetallic compounds, as illustrated for NiAl in Fig. 12.

The strengths of metals below their recrystallization temperatures are much greater than those of nonmetals.

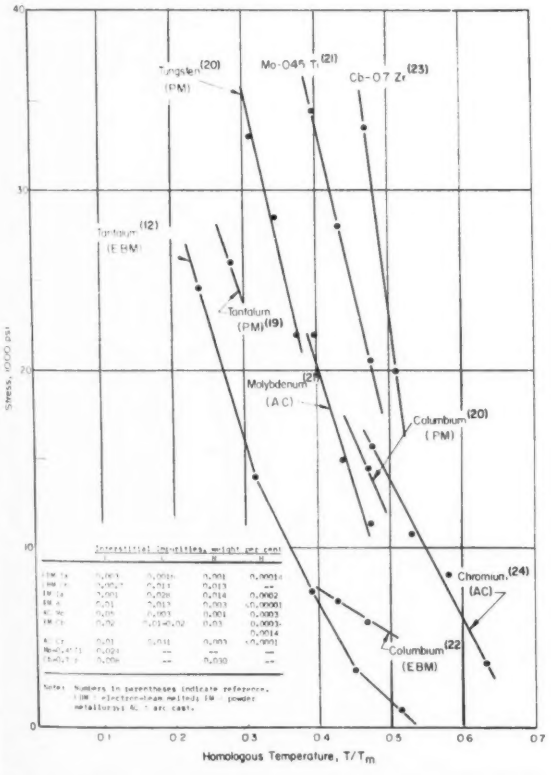

Fig. 10. 100-hour rupture strength versus homologous temperature for refractory metals in the recrystallized condition.

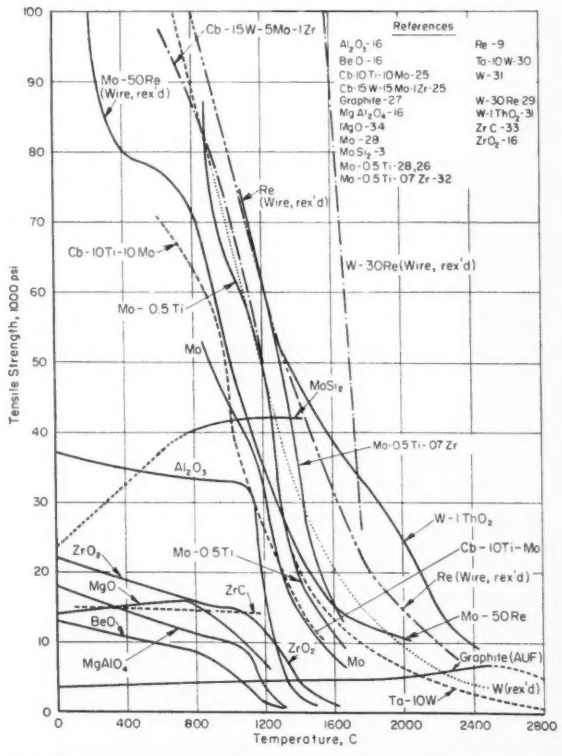

Fig. 11. Effect of temperature on the tensile strength of refractory materials

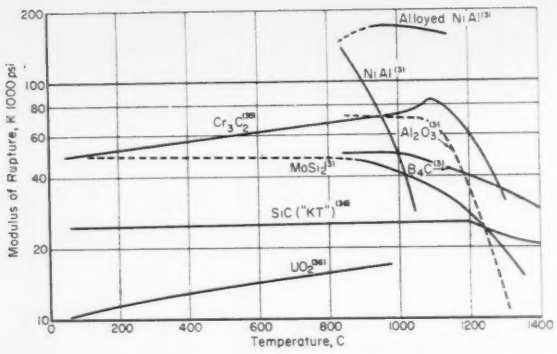

Fig. 12. Effect of temperature on the modulus of rupture of refractory materials.

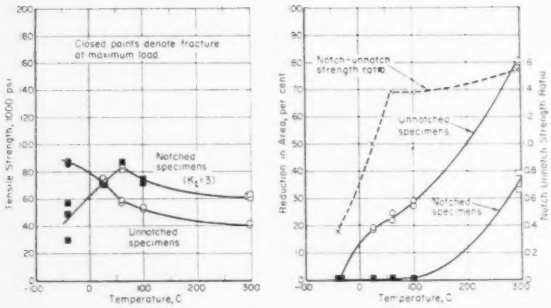

Fig. 13. Tensile properties of recrystallized molybdenum bar as a function of temperature.[18]

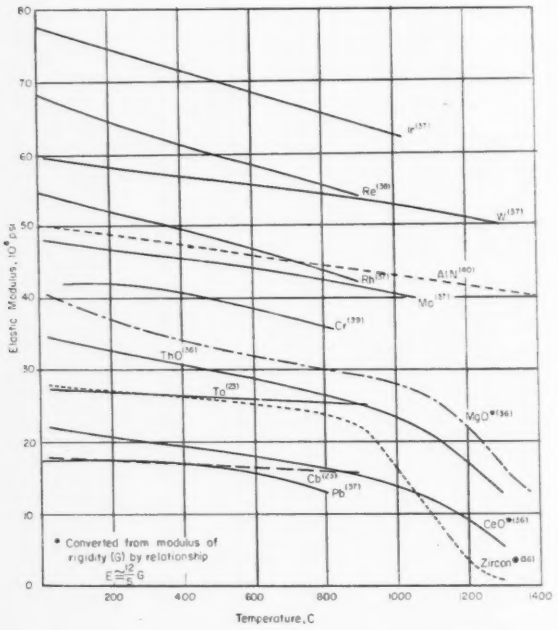

Fig. 14. Effect of temperature on the elastic modulus of refractory materials.

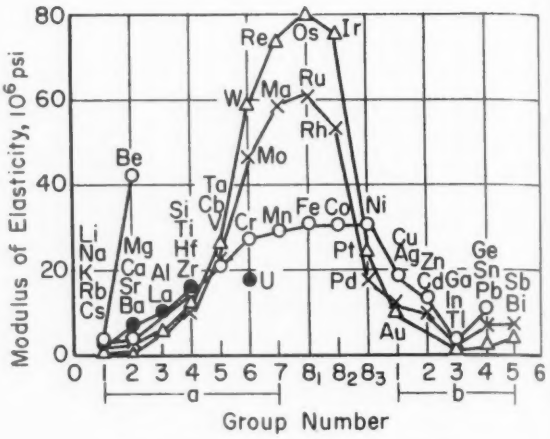

Fig. 15. Periodic variation of the modulus.[37]

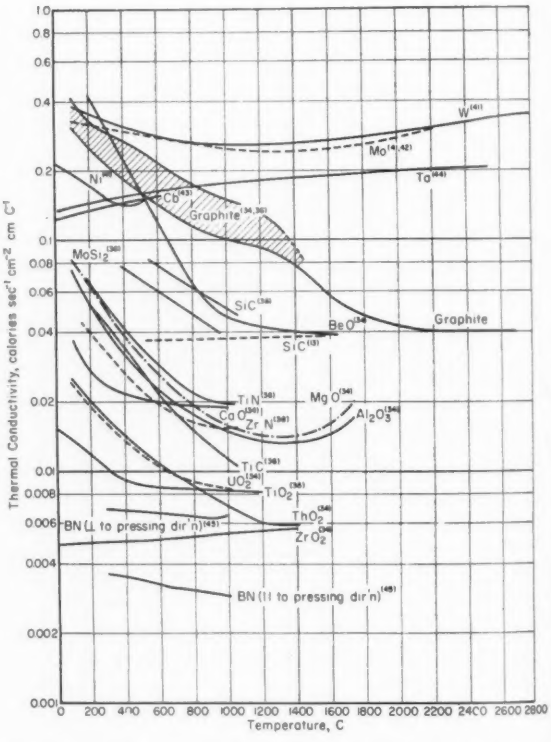

Fig. 16. Thermal conductivities of various refractory materials as a function of temperature.

Only above temperatures of 2,400°C. does graphite show a strength advantage relative to metals. The envelope of the strength-temperature curves is seen to consist of W-30Re up to 1,750°C., W-1ThO_2 to 2,500° C., and graphite at higher temperatures.

Physical Properties and Thermal Stresses

Most thermal-shock equations use the parameter $\sigma K/E\alpha$, where σ is fracture strength, K thermal conductivity, E modulus of elasticity, and α coefficient of thermal expansion. Since it is most desirable to have this parameter as high as possible, one should try to maximize strength and thermal conductivity and minimize modulus of elasticity and expansion coefficient.

The thermal-shock parameter relates to elastic stresses and no longer applies when the thermal strain exceeds the ability of the material to respond elastically to stress. If thermally induced stresses are higher, the material will deform plastically or undergo fracture. Thermal stresses generally exceed the plastic limit as a result of a high coefficient of expansion operating over a wide temperature difference. Therefore, thermal expansion is the most important factor in the parameter. Thermal conductivity also is important, irrespective of whether or not the stress exceeds the yield point of the material.

In the preceding sections, the strength properties of refractory materials were discussed. It is apparent that the metallic materials have by far the best strengths up to temperatures of about 2,400°C. The moduli of elasticity of some refractory materials are shown in Fig. 14 as a function of temperature. Most of the available data are on metals and metallic alloys. The data illustrating most of the nonmetallic materials were converted from the modulus of rigidity, assuming a Poisson's ratio of 0.2. The modulus for metals is highest for the heavy metals in the higher period groups of the periodic table, like tungsten, molybdenum, rhenium, iridium, and osmium. Fig. 15 illustrates the variation of modulus with periodic group number. The refractory metals in Group V have considerably lower moduli of elasticity, with the lighter metal columbium having the lowest of those shown. Other than for minimizing thermal stresses, it is, of course, desirable to have a high modulus of elasticity in structural applications.

The thermal conductivity of the refractory materials is illustrated in Fig. 16. It should be noted that there are three logarithmic cycles involved in the chart, illustrating the wide difference in thermal conductivity of the refractory materials. The refractory metals are notable for their high conductivity values and are followed closely by graphite, although the conductivity of graphite drops off significantly at the higher temperatures. The next group of materials are the metallically bonded carbides and intermetallic compounds. Lower still are the nitrides, and lowest the oxides. Boron nitride is an exception to the ranking of metals, carbides, nitrides, and oxides, in order of decreasing thermal conductivity.

The thermal-expansion coefficient for refractory

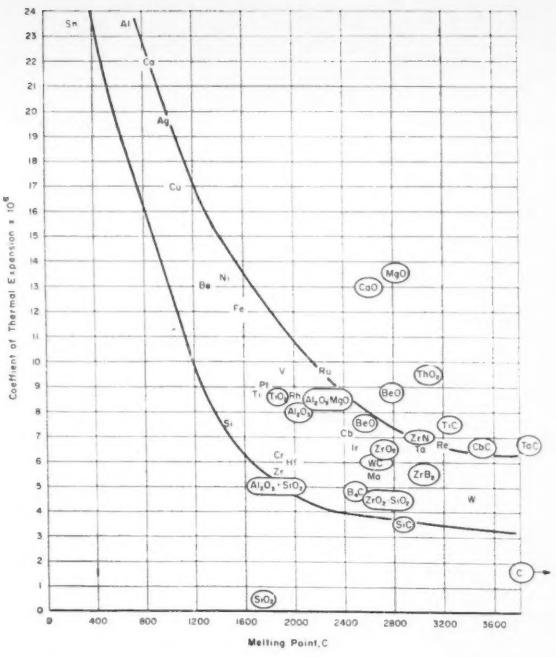

Fig. 17. Variation of expansion coefficient with melting point.

materials as a function of melting point is illustrated in Fig. 17. Lines are shown bracketing the variation of expansion coefficient for metals. There is a reasonably good correlation for metals of lower expansion coefficient as the melting point increases. Graphite appears to fit this correlation. No correlation with melting point appears to exist for the oxides, carbides, and nitrides illustrated.

As a result of the importance of expansion coefficient and thermal conductivity in thermal shock, the best behavior is found with the most refractory metals, particularly those with sufficient ductility to undergo plastic deformation as thermal stresses exceed the yield strength. For the nonmetallic materials, graphite, beryllium oxide, and silicon carbide have the most outstanding resistance.

Future Developments

The pace of research and development on refractory materials is accelerating. We can expect the present fairly elementary stage of development to be considerably advanced over the next several years.

For refractory metals, the development of alloys of superior elevated-temperature strength and, in some cases, improved oxidation resistance is practically assured. The development of coatings to protect these materials for the short excursions to the extremely high temperatures anticipated in leading edges also appears to be rather certain. Considerable work is now being done on fabricating processes for large sheets, forgings, and extrusions of these structural metals, and products of aircraft quality are to be expected. The importance of electron-beam melting, purifying, and consolidating refractory metals should increase. Powder metallurgy

should gain in importance, particularly in dispersion-type molybdenum and tungsten alloys.

In nonmetallic materials, considerable efforts, which should bear fruit, will be made to produce high-purity materials of minimum or negligible porosity. Through this means, the problems of low strength should be reduced, although it is doubtful that significant improvements can be expected in the ductility of the nonmetallic materials. At the same time, a design philosophy for ceramics will be developed whereby these materials will find increasing use in high-temperature structures, despite their brittleness. The silicides will assume major importance in protective-coatings systems for refractory materials. In contrast, greater utility of intermetallic compounds should result from exploitation of their plasticity properties. The intermetallic compounds afford a base for alloying, similar to the alloying of metals, and higher strengths at elevated temperatures should result from this. Their chief limitation will be their low melting points relative to those of other refractory materials.

Finally, basic research on refractory materials is increasing and will continue to increase. A better understanding will be obtained of the bonding in these materials and their mechanical and physical behavior. Future improvements in the performance of refractory materials can be confidently expected as a result of this considerable research effort in the refractory-materials field.

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Sonic Boom (Continued from page 24)

Conclusion

Altitude is naturally the best solution to the sonic boom problem. Not only does it bend the shock wave with its temperature gradient, it also dissipates the pressure rise with distance. Therefore, maximum altitude should be reached as soon as possible, and this can be done by climbing at subsonic speeds or at maximum practical climb path angle. During the climb, the speed must be kept below the cutoff Mach number in order to avoid an extremely severe boom on the ground. A quick reference should be made to Fig. 12 for an indication of the possibility of the boom reaching the ground. No boom should be permitted to reach the ground until the aircraft has reached an altitude of 50,000 ft. Above this altitude the aircraft will not cause objectionable pressure rises on the ground even at flight Mach numbers of 3.0.

As the descent penetrates the 50,000-ft. level, the aircraft should be at transonic speeds since the descent path angle will otherwise tend to make a strong boom a certainty. (Continued on page 45)

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Prediction of Flexibility . . .

(Continued from page 31)

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Heat Protection . . .

(Continued from page 38)

that the right choice of materials for thermal protection must be made from the knowledge of both material properties and their environmental use.

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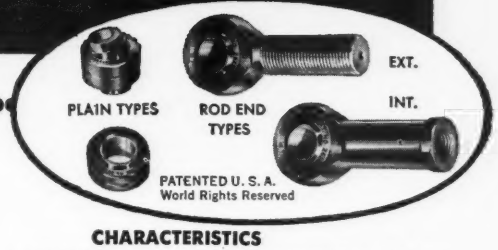

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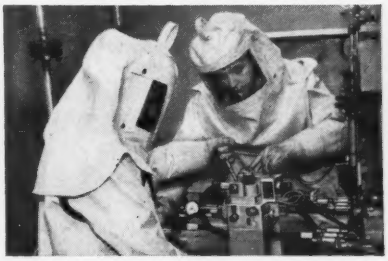

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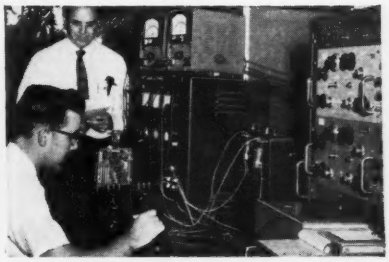

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Meet the Staff

An Aero/Space Engineering feature on personnel of the IAS

Lawrence Prezzano— *Membership Custodian*

One of New York's rarest denizens, a native New Yorker, Larry Prezzano has at his fingertips every IAS member's entree to the Institute . . . his application form. Larry joined the IAS staff as part of the Membership Department in October, 1945, when headquarters were located in Rockefeller Center's RCA Building. Since that time, he has been custodian of membership records and has supervised the processing of all applications of prospective members. This latter entails the screening and preparation of applications with accompanying data for submission to the Membership Committee.

Now a resident of the borough of Queens (one of New York City's five), Larry is blessed with the *sine qua non* of the city dweller's rarely fulfilled passion . . . a place to have a garden . . . and spends much of his spare time there. He is also a fishing devotee and casts his line as often as time permits. K.B.

IAS News — News of Members

Harry Archer (M), formerly Eastern District Supervisor for Champion Spark Plug Co., has been appointed Aviation Marketing Assistant for the company.

Carl F. Baker (F) has been named Quality Manager of Chandler Evans Corp. Prior to joining Chandler Evans, Mr. Baker was Quality Manager for Hamilton Standard Division of United Aircraft Corp.

Rolf D. Buhler (M) has been appointed Vice-President of Plasmadyne Corp., a subsidiary of Giannini Scientific Corp. Dr. Buhler formerly served as Head of Plasmadyne's Physical Gas Dynamics Division.

Robert E. Beach (A), Corporation Counsel for United Aircraft, has been elected a Vice-President of the corporation.

G. E. Burkheimer (M), formerly Chief of Technical Services, Advance Engineering, Convair, Division of General Dynamics Corp., has been named Assistant Chief Engineer, Advance Engineering, for the Division.

Charles H. Chatfield (F), Secretary of United Aircraft Corp., has been elected a corporate Vice-President.

H. H. Christensen (AF) has been named Manager—Advance Space Navigation Engineering for the Advance Engineering Operation of General Electric's Light Military Electronics Dept. Mr. Christensen was formerly Manager—Flight Control Application Engineering for the department.

Robert M. DeHaven (M) has been appointed Manager of the Flight Test Division of Hughes Aircraft Co. He was formerly Associate Director of the Division.

Douglas T. Egbert (M), formerly Washington, D.C., Engineering Representative for Northrop's Norair Division, has been appointed Director of Astronautics and Research Marketing for the Division.

Richard G. Folsom (AF), President of Rensselaer Polytechnic Institute, was recently elected to the Board of Directors of Air Reduction Co., Inc.

E. W. Fuller (M) has been appointed Manager of the newly reorganized Special Products Division, Nuclear Products Branch, of Lockheed Aircraft's Georgia Division. Mr. Fuller was previously Equipment and Maintenance Staff Engineer.

Edwin P. Hartman (M) has been assigned to the Department of Supply of the Commonwealth of Australia as the NASA Senior Scientific Representative. Mr. Hartman was formerly with the Technical Division of NASA's Western Operations Office.

Benjamin J. Kaganov (AF), formerly Director of Research and Advanced Development for Canadair Ltd., a Division of General Dynamics Corp., has joined Canadian Aviation Electronics Ltd. in the newly created position of Executive Vice-President.

L. J. Lekus (AF), a Proposal Evaluation Engineer for General Electric's Missile and Space Vehicle Dept., has been appointed Manager of Business Programming in the Department's Marketing Section.

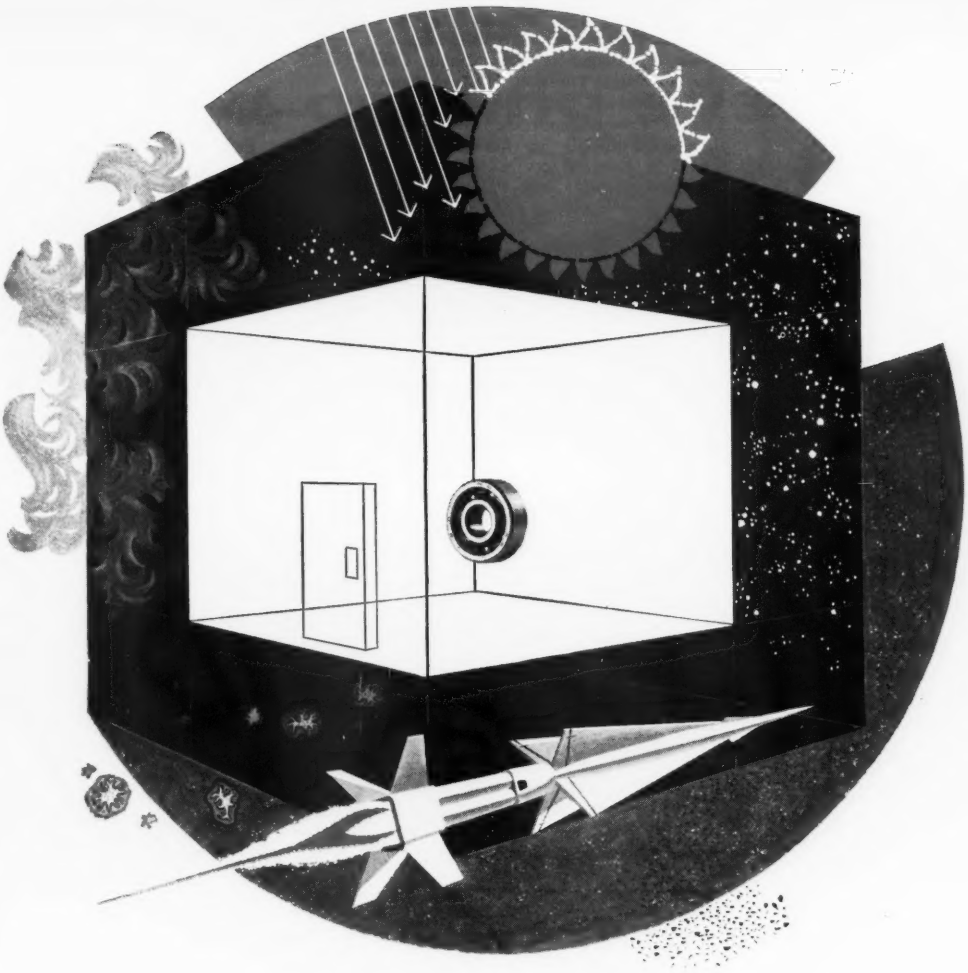
Stanley R. Lipson (A) has joined General Electric's Missile and Space Vehicle Dept. as Systems Engineer—Configuration, in the Advanced Re-Entry Vehicle Engineering Operation. He was formerly Advanced Design Project Aerodynamicist with the Fairchild Aircraft-Missile Division.

J. J. Marcinek (M), formerly Head of Aerophysics and Mechanics, Convair, Division of General Dynamics Corp., has been named Chief of Pre-design and Physics for the Division.

G. J. Rauschenbach (M), former Director of Requirements for The Martin Company's Denver Division, has been appointed District Representative of Martin's Huntsville, Ala., office.

Iden F. Richardson (M) has been appointed a Vice-President of Hughes Air-

Bertram Mintz (M) has been named Chief Application Engineer for Hughes Tool Company's Aircraft Division. Prior to joining Hughes, Mr. Mintz was Eastern Representative for R&D for the Marquardt Company.



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Jean R. Nelson (M) has been named Director of Engineering by Winzen Research, Inc. Prior to oining Winzen, Mr. Nelson was Project Engineer for the Aeronautical Division of Minneapolis-Honeywell Regulator Co.

craft Co. He also continues to serve as Manager of the company's Commercial Products activities.

William L. Rogers (M), former Vice-President, Azusa Operations, Aerojet-General Corp., has been promoted to Vice-President, Azusa Plant, encompassing responsibility for the entire plant including all service functions as well as operating activities.

Lt. Gen. Bernard A. Schriever, USAF, Commander, ARDC (AF), was awarded on May 2 the General H. H. Arnold Trophy of the Arnold Air Society, a nation-wide organization of Air Force cadets. The award, for "countless contributions to world peace," stated that General Schriever, "in addition to being the leader among leaders, has made countless contributions to world peace as a leading architect of this nation's missile power."

Ronald S. H. Toms (AF), formerly Director of Wiancko Aeronautics, has joined Electro-Optical Systems, Inc., as a Senior Scientist, working on development of an ion motor.

George E. Tubb (M) has been named Director of Marketing for Electro-Tec Corp. Mr. Tubb was a Management and Marketing Consultant prior to joining Electro-Tec.

G. T. Willey (M), Vice-President and General Manager of The Martin Company's Orlando Division, has been named to the Board of Directors of the Associated Florida Private Colleges. He will join the Board officially on January 1, 1961. AFPC includes Barry College, Florida Southern College, Rollins College, and Stetson University.

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Corporate Member News

• **Fairchild Camera and Instrument Corp.** has announced construction of an Environmental Test Laboratory, geared to the testing of complete intelligence gathering and other systems under space environments.

• **General Applied Science Laboratories, Inc.,** has moved to new quarters at Merrick and Stewart Avenues, Westbury, L.I., N.Y.

• **General Electric Co.** broke ground for its Space Technology Center in Valley Forge, Pa., on April 21. The first phase of the construction plan is expected to be completed by the end of 1961. This phase will consist of a number of integrated buildings, including a headquarters for the Missile and Space Vehicle Dept., Space Sciences Laboratory, and an engineering and development facility.

• **Thompson Ramo Wooldridge Inc.** has established an International Division to coordinate the company's foreign operations. The division will be located in the west coast headquarters of Thompson Ramo Wooldridge, Canoga Park, Calif. George W. Fenimore has been appointed General Manager.

• **United Aircraft Corporation's** subsidiary, United Technology Corp., has moved to new headquarters at 587 Mathilda Ave., Sunnyvale, Calif. The company's new mailing address is P.O. Box 358, Sunnyvale.

ATTENTION IAS MEMBERS!

In accordance with plans reported in the June issue of Aero/Space Engineering, *the October, and first, issue of IAS News (prepared in newsletter format) will be published and mailed to the Institute's more than 16,000 graded members on Sept. 15 and on the 15th of each succeeding month.*

Plans to increase the technical article content of Aero/Space Engineering *will take effect with the October issue, which will continue to be published and mailed on the first of each month to IAS members plus several thousand other subscribers.*

This year's IAS Roster Issue of A/SE will appear next month.

IAS Sections

Cleveland-Akron Section

Expandable Structures

Dr. Robert S. Ross, Manager of the Aeromechanics Research and Development Dept., Goodyear Aircraft Corp., addressed the April 19 dinner meeting on the subject of **"Applications of Expandable Structures to Space and Re-Entry."**

Illustrating his discussion by the use of slides, moving pictures, sketches, charts, and samples, Dr. Ross told of inflatable airplanes and deceleration balloons. He also discussed ultra-high-altitude aircraft, re-entry vehicles, solar collectors, space stations, lunar structures and expandable antennae, all of which may be potential applications for expandable structures.

Preceding the dinner, the Babcock & Wilcox Co. Boiler Division plant was toured. Principal products of this division are boilers and steam generating equipment for public utilities, electrical power stations, industrial power and process plants, heating plants and marine service.

R. K. CHAMBERLAIN
Secretary

Detroit Section

Rocket Scientist Before Joint Meeting

Combining knowledge of the space and missile programs of this country and foreign countries, **Kurt Stehling** addressed the April 5 joint meeting of the Detroit Section of the IAS and the Michigan Aeronautics and Space Association. Mr. Stehling, Scientist for Rocket Propulsion, Office of Program Planning and Evaluation, NASA, discussed **"Ancillary Systems for Space Vehicles."**

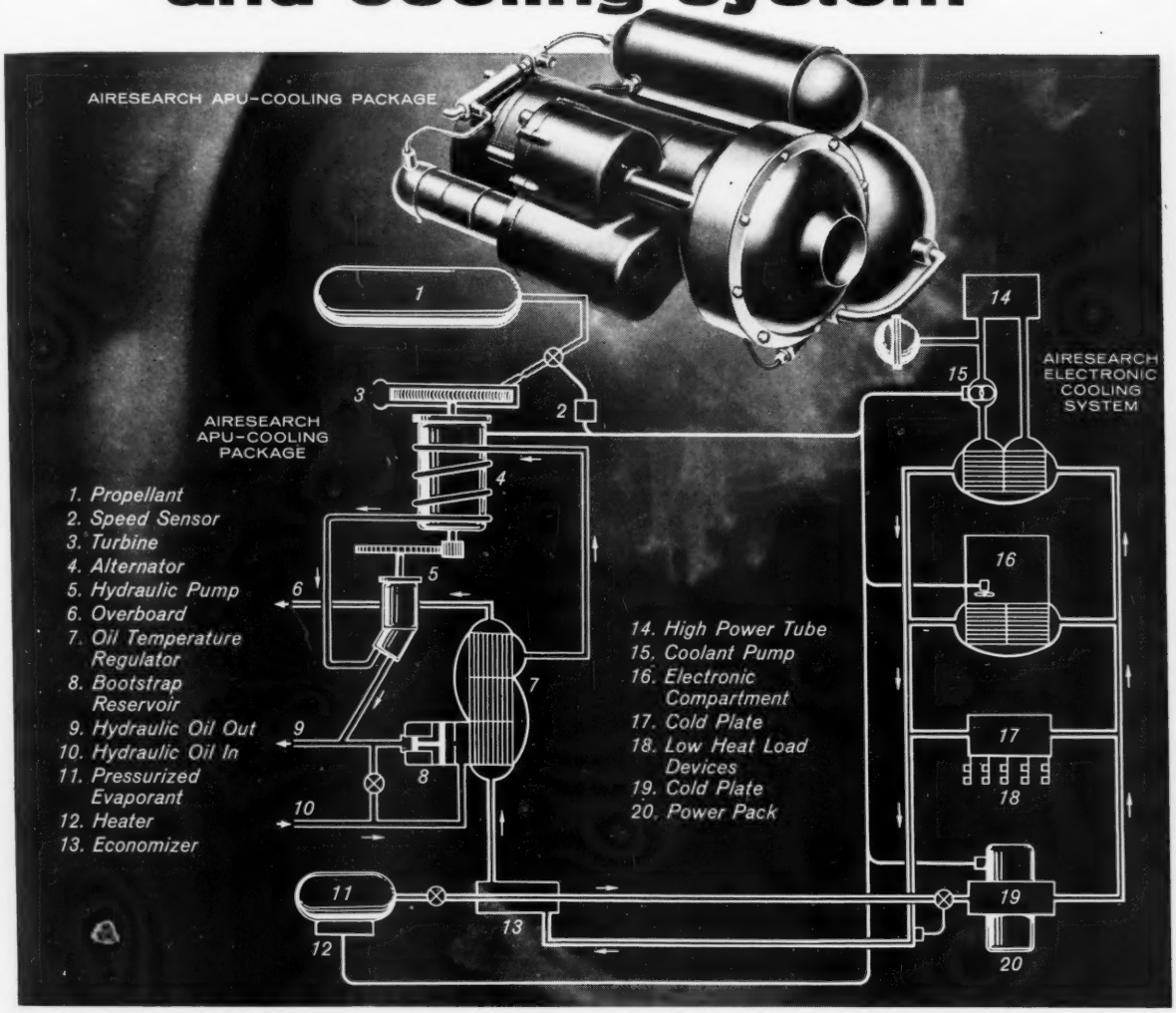
Giving a general review of the NASA space program for the coming years, Mr. Stehling discussed major vehicles planning with a brief description of each. The vehicles discussed included Saturn, Scout, Centaur, Agena, Nova, Juno, Delta, Rover, Orion, Kiwi, and the component development effort required to support these major programs. A considerable amount of detailed information on the design aspects and performance characteristics of these units was presented.

In addition to the overall missile systems, Mr. Stehling discussed accessory power systems and propulsion means. Advanced propulsion concepts, such as electromagnetic, and various nuclear systems, including the utilization of atomic and hydrogen bombs, were covered as well as the conventional chemical and electrical propulsion systems.

During the discussion period, Mr. Stehling reviewed the current status of the plug nozzle programs, fuel cells, satellite stabilization and rendezvous, stage operation, the AEC work on the Kiwi and Rover programs, and Russian Space programs.

FRANK L. MONCHER
Secretary

Integrated accessory power and cooling system



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World leader in the design and manufacture of cooling and accessory power systems, AiResearch has delivered more missile APUs than any other company, and is the leader in advanced electronic cooling systems for aircraft, missiles and spacecraft.

AiResearch design and manufacturing experience in these two fields includes: liquid and solid propellant APUs; hydraulic and hot gas actuators and control systems; 3200 and 400 cycle alternators; cold plates; expendable and closed cycle gas and liquid cooling systems; cryogenic cooling systems.

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Los Angeles Section

Aviation to Atoms Covered in 2-Month Period

Dr. Charles A. Barth, Senior Research Physicist, Jet Propulsion Lab., prepared the paper given at the April 12 Specialists Meeting. In discussing **"The Role of Atoms in Aeronomy,"** Dr. Barth reviewed the present knowledge of the structure and composition of our atmosphere by discussing the geophysical laws involved, the use of atomic physics to measure properties, and the results of direct measurements using rockets. The specific measurements of pressure, temperature, and oxygen atom distribution by interpretation of "airglow emissions" were emphasized.

▶ A special meeting was held on April 2 for the purpose of **"A Tribute to Roy Knabenshue."** Mr. A. Roy Knabenshue, who passed away on March 6, 1960, was an early balloonist and was one of the first dirigible pilots in the U.S. He piloted the Baldwin dirigible in the St. Louis World's Fair of 1904. He later built and flew passenger dirigibles in Los Angeles and Chicago. He was also promotion manager for the Wright Brothers in their public exhibition tours, which included airlifting the President of the United States, Theodore Roosevelt.

The IAS program featured telephone-to-P.A. system greetings form General Frank Lahm, first U.S. military pilot and a tributary speech by A. E. Raymond, Vice-President of Douglas Aircraft Co., now retired. These and many other friends of Mr. Knabenshue participated in or were present at the program. Films of Mr. Knabenshue's flights in St. Louis and Chicago were shown as well as of many Early Bird flights from the period before World War I, including Mr. Knabenshue's activities with the Wright Brothers. The program enjoyed the interest and cooperation of the Early Birds, OX-5 Club, American Aviation Historical Society, Silver Wings, and Society of Experimental Test Pilots.

▶ The 1960 Minta Martin Lecture was presented to the Los Angeles Section on March 31. **Brigadier General B. S. Kelsey's** paper on **"Size Considerations in Optimum Aircraft"** traced historical patterns to show a geometric progression with a ratio of 2 fitted the size of successful aircraft. The use of such progression philosophy as a planning, design, and evaluation tool was recommended.

▶ **Maj. Gen. J. W. Sessums,** USAF (Ret.) and Chairman of the Board, Grand Central Rocket Co., was speaker at the March 17 classified dinner meeting. General Sessums discussed **"Advanced Rocket Propulsion Systems"** covering the spectrum of forthcoming rocket techniques as applied to space boosters. He included a review of the Coanda Effect as influencing rocket performance on the atmosphere. Movies of rocket throttling tests were also presented in the survey.

S. J. COLBY, *Secretary*

New York Section

Rocket Power for the X-15

Harold Davies, Manager of Project Engineering for Thiokol Chemical Corporation's Reaction Motors Division, presented a discussion entitled, **"Development of the XLR-99 Rocket Engine for the X-15 Aircraft"** before the April 14 dinner meeting.

The XLR-99 rocket engine for the X-15 aircraft, the largest rocket engine for manned aircraft yet developed, is provided with propellants by a turbo-pump and the entire system is fully automatic in starting and shut-down cyles. The engine is of 50,000 lb. maximum thrust (1/2 million horsepower at X-15 flight speeds) and capable of throttling to the 25,000 lb. level, with successive restarts in flight. The propellants are liquid oxygen and anhydrous ammonia with decomposed hydrogen peroxide as the turbine drive.

Mr. Davies traced the development of the engine from its initial specification through development to the successful completion of preflight rating tests. Inherent in the initial design philosophy was the need for the engine to function or shut down safely under any conceivable

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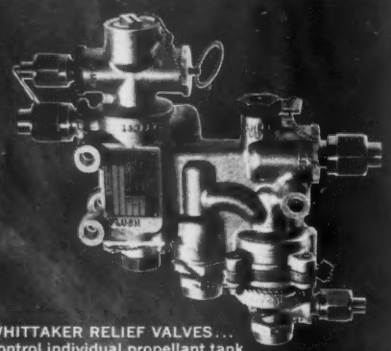

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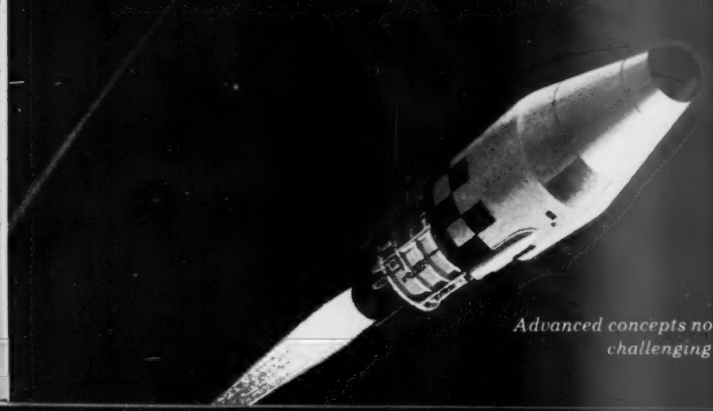

Planned Reliability is important to the success of the Discoverer Satellite Program. When the Thor-Agena launch vehicle thunders off the pad toward orbit position for the second stage, valves and fluid control systems must function with predetermined accuracy to assure successful positioning and stabilization of the satellite.

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single malfunction. The major elements of the system were described and the effects of the single malfunction philosophy in areas such as component redundancy and automatic malfunction monitoring.

The preflight rating test program was reviewed and shown to require very severe conditions for rocket engines. The requirements called for firing in all attitudes and demonstrating safe operation under any conceivable single malfunction. Two engines were required to accumulate 60 minutes of running time each, while a third engine was used for vibration testing followed by approximately 15 minutes of running time. These arduous tests have been successfully completed and the engine is now awaiting flight in the X-15 aircraft.

Mr. Davies stated that although not yet fitted with the large new engine, the X-15 has already reached 130,000 ft. altitude and a speed of more than Mach 2.5.

R. M. WOODHAM, *Vice-Chairman*

Omaha Section

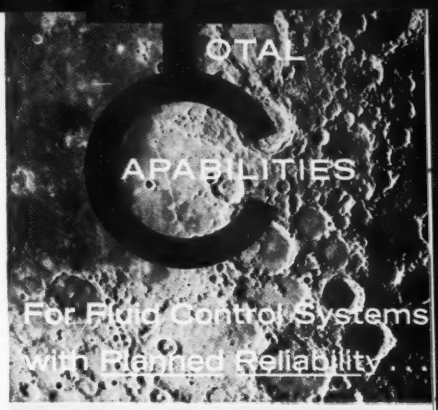
Low-Drag BLC Studies

"The Applications of Low-Drag Boundary-Layer Control" was the subject of a presentation by **Dr. Werner Pfenninger** of the Northrop Corp. at the April 21 luncheon meeting.

Dr. Pfenninger, who heads Northrop's LD-BLC research and development, discussed the results of eleven years of USAF-sponsored work conducted by the company's Norair Division. Initial studies were accomplished by applying suction to various shapes and surfaces in wind tunnel tests. These studies were verified by over 250 flights with a slotted metal glove installed on the upper wing surface of a F-94 aircraft. Full laminar flow under a variety of conditions was demonstrated in these flights.

Dr. Pfenninger outlined the physical nature of the boundary layer and the benefits to be accrued in terms of increased aircraft performance by the use of BLC control. He emphasized that particular attention in designing a BLC suction system must be given to the slots to minimize the loss of kinetic energy of the boundary layer as it sucked into the ducts. He also described the Northrop-developed manufacturing processes for applying LD-BLC to wings and tail surfaces.

Advancing from the straight wing, Dr. Pfenninger and his staff now are engaged in applying their knowledge of BLC to swept wings. Currently, wind tunnel tests are being conducted on models varying sweep angle from 30 to 60 deg. Swept wings compound the problem of boundary layer removal due to the tendency of the air to flow outboard.



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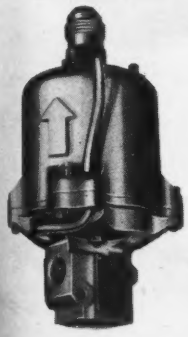

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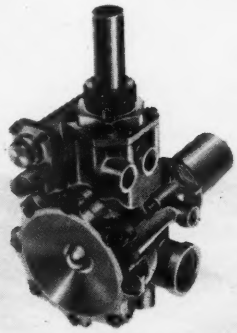

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Dr. Pfenninger discussed methods of coping with this crossflow problem and cited the results of Northrop's wind tunnel tests.

In summation, Dr. Pfenninger stated that Northrop's work has "verified that laminar flow can be maintained on complicated surfaces by means of boundary-layer suction, thus leaving the designer of a laminar suction airplane an increased number of design tools at his disposal."

MICHAEL J. MCALISTER, *Secretary*

San Diego Section

March, April Meetings Varied in Subject Matter

Kenneth E. Newton, Chief Test Conductor-Atlas Program, presented an informal discussion before the April 21 dinner meeting. In his presentation, **"Russia Seen by a Tourist",** Mr. Newton described his reactions based on his 1959 visit to the USSR as part of a National Aeronautics Association team sent for the purpose of discussing private aviation.

▶ The April 7 technical meeting featured a discussion on **"Jet Expansion and Base Recirculation Analysis"** by **Dr. J. M. Bowyer, Jr.,** Design Specialist in the Fluid Dynamics Group at Convair. Dr. Bowyer described two methods of analysis which he had applied to the problem. In the first, exact solution of the problem, idealized to one of axial symmetry, was obtained by the method of characteristics. This solution is restricted to adiabatic but rotational flow of a free jet into a quiescent, supersonic or hypersonic stream. Shock waves are included as they originate and propagate through the flow. In the second part, a similarity analysis of the problem was obtained from the governing differential equations and accompanying boundary conditions.

Application of the first method, in order to determine particular flows in the vicinity of a missile base, and of the second, in order to devise valid model tests of complex missile configurations, were described. Corresponding results were presented.

▶ **"Solar Flare Radiation Hazard to Manned Space Flight"** was the subject of a presentation before the April 29 Space Science meeting. **Donald Robey** of Convair-Astronautics presented information on radiation levels that result from solar flares and showed how the intensity and frequency of the flares vary periodically. The mechanism of solar flares was described as it is currently understood—it was pointed out that relatively little is known about this phenomenon. At the conclusion of his talk, Mr. Robey showed movies of solar flares in action that had been photographed with the aid of high-powered telescopes.

▶ **Dr. M. L. Rosenzweig,** a member of the Propulsion Research Dept. of Space Technology Laboratories, Inc., addressed the March 24 meeting on the subject of **"Materials for Ablating Heat Shields."** He first presented an introduction to the characteristics of the various ablation processes and a description of the physical properties of several types of materials.

The parameter most often used to characterize ablation materials (Q^*, "effective heat of ablation") was defined and simple formulas for its evaluation were derived. Several different heat shield applications were suggested, and the differences in the material properties required to perform the missions were pointed out. Methods currently used to test and evaluate ablating materials were discussed. The talk was supplemented by a color movie of tests on several ablation materials.

▶ The March 22 meeting was addressed by **E. C. Holleman** and **H. R. Greider.** Mr. Holleman, an aeronautical research engineer at NASA's High Speed Flight Station, Edwards Air Force Base, spoke on **"Utilization of the Pilot in the Launch and Injection of a Multistage Orbital Vehicle."** Representing multistage rocket launchings by fixed base and centrifuge simulators, he investigated the capabilities of the human pilot as the primary controller of the multistage rocket. Included in these tests were the effects of the launch acceleration profile on the task of controlling two- and four-stage vehicle launches.

Results were good—with adequate support system the only effect on the pilot due to launch acceleration was loss of peripheral vision. By breathing 100 per cent oxygen the pilot was able to withstand 14*g*. Little effect of the pressure suit was noted on the pilot's performance. The test concluded that if the pilot were placed in a vehicle throughout the launch, he would be able to cope with emergency situations. Further research necessary for maximum utilization is to be made.

Mr. Greider, who for the past three years has been working on the development of the Mercury environmental control and life support systems at McDonnell Aircraft Corp., discussed design criteria and operational methods for the project. Presenting the company's approach to the design and various problems encountered during the program, Mr. Greider included a complete description of the operation starting two hours before blast-off—when the astronaut first enters the capsule, initial launching, climb-out, separation, orbit, and recovery.

WALTER P. ROBINSON

San Francisco Section

Orbiting Astronomical Observatory

Robert M. Crane, Chief, Aero-Thermodynamics Div., Ames Research Center, NASA, discussed some of Ames' activity in the NASA Space Program before the April 21 meeting. Title of his discussion was **"The NASA Program for an Orbiting Astronomical Observatory."**

Mr. Crane pointed out that NASA has three major astronomical programs: (1) the Solar Physics Program, (2) the Galactic Astronomy Program, and (3) the Radio Telescope Program. The Orbiting Astronomical Observatory is one phase of these astronomical programs and is under the direction of Dr. Nancy Roman in the NASA Office of Space Flight Programs. The project manager is Robert Ziemer of the Goddard Space Flight Center. The Ames Research Center role is primarily one of preparing contractor bid specifications for the Orbiting Astronomical Observatory.

Mr. Crane's remarks centered mainly on the satellite for the galactic astronomy and solar physics programs. A major objective in these programs is to get a telescope, remotely controlled, into space so that stellar information can be collected outside of the absorptive influence of the earth's atmosphere. Mr. Crane pointed out that at present this approach appears to be more feasible than utilizing a manned platform because the former will not have the momentum disturbances which a man moving on the platform would create. The external torques that a telescope-platform control system has to compensate for, he said, are as follows: (1) solar radiation, (2) gradients due to the earth's gravitational field, (3) electrical coupling of the satellite electrical-systems magnetic field with the earth's magnetic field, and (4) aerodynamic forces at low altitude (400 miles). The external torques from these combined sources are not expected to exceed a 100 dyne centimeter control capability both on coarse and fine tracking. Torque specifications will include, moreover, a requirement for fine control to 0.1 second of arc.

Ames Research Center has considered the engineering aspects of a carrier vehicle for a telescope in space as falling into five broad categories: (1) attitude control, (2) power systems, (3) thermal balance, (4) communication aspects, and (5) vehicle layout considerations. Mr. Crane noted that several systems are being considered for creating the necessary torques; the reaction wheel, the gyro wheel, vapor jet and cold-gas jet. These techniques, he noted, present a smaller problem than the techniques for detecting minute angular errors. Solar and star trackers are being considered, and these will, of necessity, have to perform their functions by time-sharing certain wave lengths with the observational program being carried on. Special attention is being given to methods for minimizing the amount of work required of the control system. A torque of about 20 dyne centimeters is expected to accrue from the satellite being constantly exposed to solar radiation pressure, a force field roughly equivalent to about one-tenth of an ounce per acre. He noted too, that very small satellite geometrical asymmetries (1 part in 1000 in moment of inertia) can increase significantly the work load for the control system. Power requirements are estimated to be about 100 watts normally demanded, with a peak requirement of about 200 watts. Special provisions will be required for keeping hardware at temperatures of optimum performance, e.g., photo detectors will have to be kept at $-80°C$. and batteries at room temperature. Because the telescope is desired to be orientated in any arbitrary direction in space, the command system for providing this orientation will have to be rather elaborate. He envisioned that data

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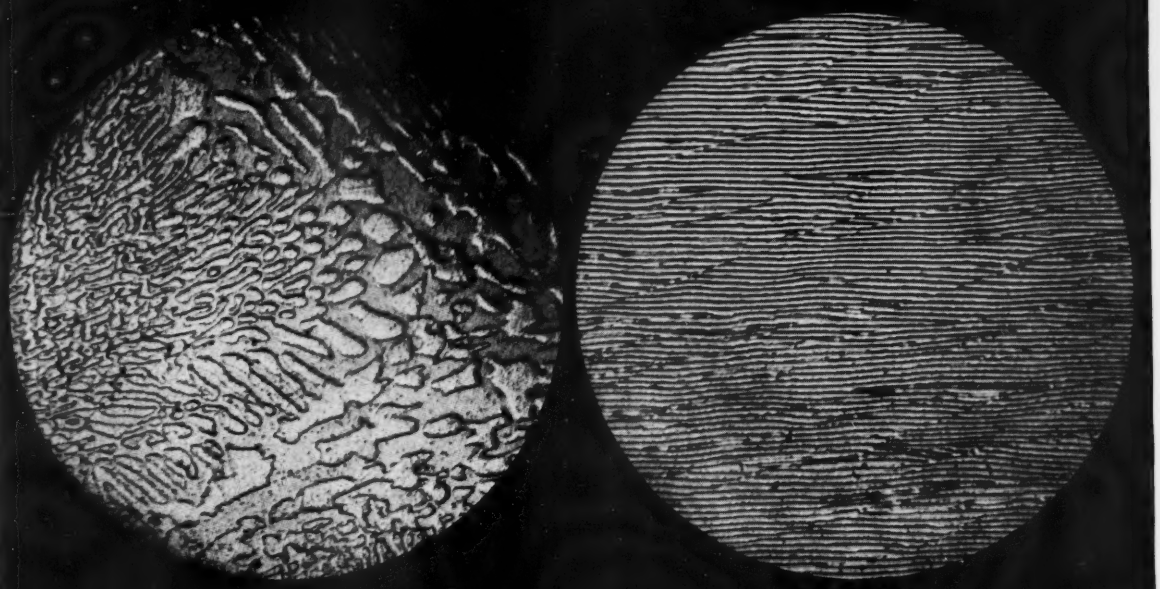

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(Left to right) Section Chairman Victor M. Ganzer, guest speaker A. Scott Crossfield, and George C. Martin, Vice-President & Assistant General Manager, Aero-Space Division, Boeing Airplane Co., at dinner preceding April 11 technical meeting of Seattle Section.

would be stored temporarily before being transmitted to earth.

NORMAN BERGRUN, *Secretary*

Seattle Section

Flight Testing the X-15; Chairman Ganzer on Leave

A. Scott Crossfield, North American Aviation's Chief Test Pilot for the X-15 research aircraft, was guest speaker at the April 11 meeting. After a few introductory remarks concerning the concept of the X-15 program and the other flight research programs that preceded it, Mr. Crossfield presented a motion picture covering the first gliding and powered flights. These films included air-to-air pictures of the drop, free-flight, and landing phases of the operation. The landing approach characteristics of the airplane as well as its high landing speed and attitude were particularly dramatic.

Following the film, Mr. Crossfield described the X-15 structure, systems, engines, and flight characteristics in considerable detail.

Dr. Harold Martin, Chief Executive Officer of the Department of Aeronautical Engineering at the University of Washington, and a member of the sections Advisory Management Committee, announced that Section Chairman **Vic Ganzer** was leaving soon on an extended recreational tour before returning to his teaching position at the University of Washington in the Fall. Mr. Ganzer was presented with luggage by the officers and members of the section. His duties as Section Chairman will be assumed by Vice-Chairman Yusuf Yoler during his absence.

JOHN K. WIMPRESS, *Secretary*

Texas Section

Southwestern Region Student Competition

The Eighth Annual Southwestern Student Competition, conducted by the Texas Section of the IAS, was held in Dallas on April 28–30 at the Adolphus Hotel. Seventeen undergraduate and graduate students representing thirteen colleges throughout the South, Southwest, and Middle West delivered papers. The competition was sponsored by the Minta Martin Aeronautical Student Fund of the IAS, and four local aircraft companies—Bell Helicopter Corp., Chance Vought Aircraft, Inc., Convair Div. of General Dynamics Corp., and Temco Aircraft Corp.

Papers presented in three undergraduate and one graduate session dealt with diverse subjects, including aerodynamics, structures, rockets, gliders, jet transports, and jet engines. Luncheons held on Thursday and Friday presented leading engineers from sponsoring companies speaking on the general theme, **"The Relationship Between the Engineer and Industry." Bartram Kelley,** Vice-President of Engineering for Bell, discussed the background reorganization of Bell, and the goals an engineering student or engineer should have to warrant additional schooling necessary for obtaining a master's degree. **E. V. Marshall,** Project Manager-Dyna Soar, Chance Vought Aircraft, Inc., spoke on the changing picture of airfoil requirements from the 1920's up to and through the present, as well as outlining the problems of thermal heating from a microscopic nature, including thermal stress changes due to variations of heating within the basic structures. **Howard Marx,** Manager of Development Planning, Temco Aircraft Corp., dealt with the changing nature of the aerospace industry in light of the decreased emphasis on manned aircraft and the great increase in the scope and complexity of today's technology. **Dr. E. L. Secrest,** Chief of Applied Research, Advanced Design Section, Convair, gave an account of the nature and role of research, both pure and applied, in the field of aerospace technology.

A barbecue dinner Thursday evening at Southern Methodist University was followed by a Specialists Meeting with Joseph A. Walker, NASA's test pilot for the X-15 research airplane, as guest speaker. Mr. Walker discussed his experiences flying the X-15 and the plane's design.

Participants in the competition were taken on a tour of the plant facilities at Bell, Chance Vought, Convair, and Temco on Saturday. That evening, the Awards Night Dinner was held at the Adolphus Hotel. Principal speaker for the evening, **J. R. Clark,** General Manager, Astronautics Div., Chance Vought Aircraft, Inc., spoke on **"Impact of Advances in Technology on the Aerospace Industry."** He outlined the problems and challenges of the times of everchanging technical requirements.

Final event of the competition was the presentation of awards to winning students by IAS President, Lt. General Donald L. Putt, USAF (Ret.).

Undergraduate Division winners were: First prize—**Arnold E. Ebneter,** Agricultural and Mechanical College of Texas, for **"Preliminary Design of an FAI Class 1 Airplane and Plans for Establishing International Distance Records"**; second prize—**James H. Seely,** University of Colorado, for **"A Mechanical and Operational Analysis of the Turbo-Athodyd Engine"**; third prize—**John R. Johnston,** University of Wichita, for **"A Parametric Performance Analysis of a VTOL Wing-Rotor Aircraft."** Graduate Division winners were: First prize (tie)—**David A. Pirie** and **Geore W. Stone,** Georgia Institute of Technology, for **"The Response Characteristics of Simulated Pneumatic Missile Pressure Sensing Systems Subjected to Continuous-, Impulse-, and Shock-Type Inputs,"** and **David L. Kohlman,** University of Kansas, for **"A Theoretical and Experimental Investigation of a High Speed Light Gas Gun."**

C. A. ROGERS, JR., *Publicity Chm. Texas Section Student Competition*

Twin Cities Section

Hill Award Winner Honored at Banquet

Dr. James A. Van Allen, Professor and Head of the Department of Physics and Astronomy of the State University of Iowa, and 1959 winner of the Louis W. Hill Space Transportation Award, addressed the Twin Cities Section at a banquet in his honor on April 14. Dr. Van Allen's subject was **"Man's Venture into Space."**

Dr. Van Allen indicated that the outlook for space exploration by the United States in the future has picked up considerably in the last couple of years. Stating that "we have been shamefully" disgraced during the past two years," he then said that U.S. scientists are now "pulling themselves together." Though the United States has had trouble matching Russian single-mindedness and determination, Dr. Van Allen felt that it was doubtful that Russia's space program has the depth and diversity of ours. The technological problems involved are tremendous and research is being conducted on a very high level with extreme care to detail.

Dr. Van Allen felt that solar travel is in the distant future but will eventually come about; putting men into space is only the first step.

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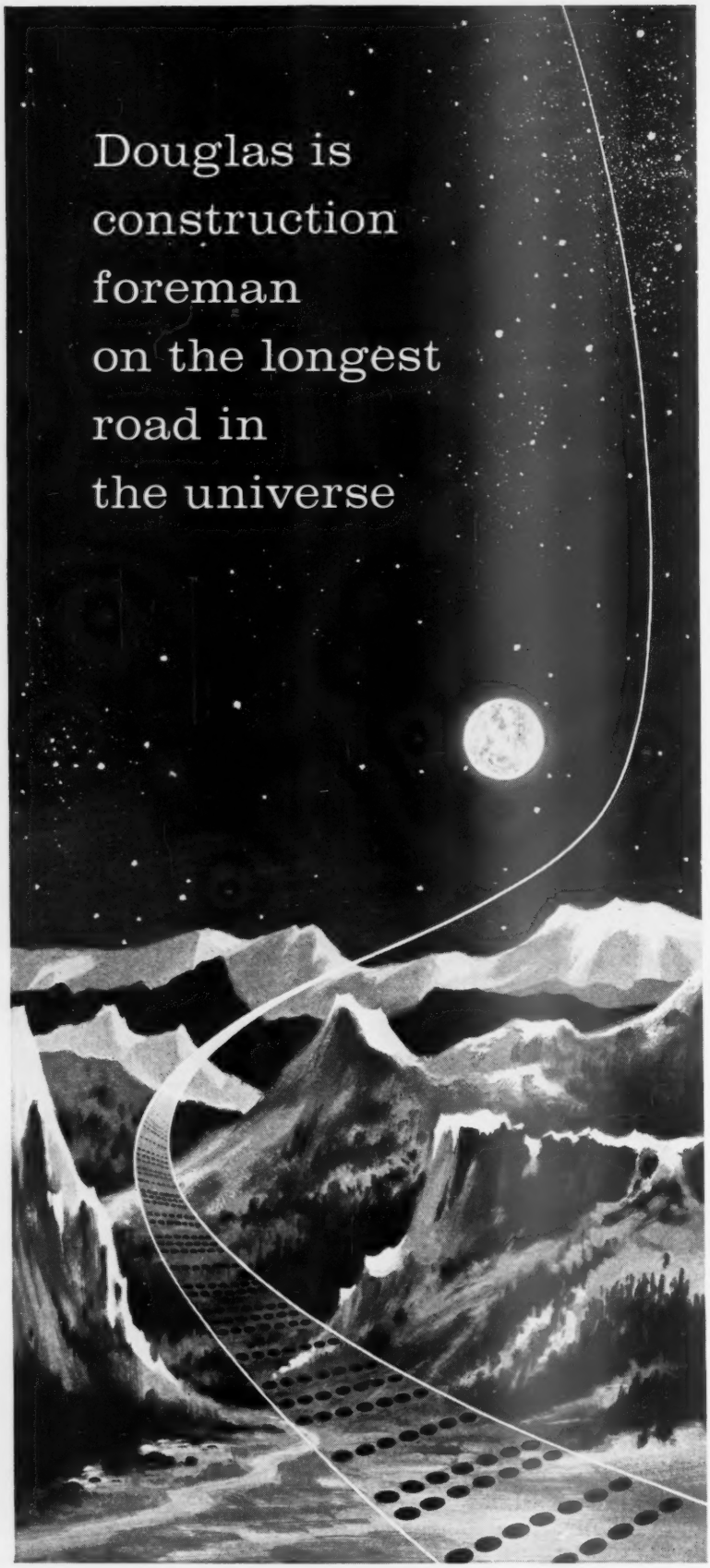

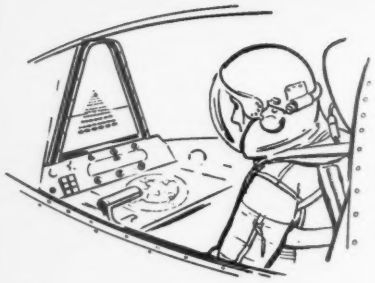

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For a listing of the principal periodicals received in the IAS Library, please refer to the January, 1959, issue.

The AERO/SPACE ENGINEERING INDEX, formerly the AERONAUTICAL ENGINEERING INDEX published since 1947, provides an annual cumulation of the materials reviewed in this section.

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Acoustics, Sound, Noise

Fuselage Sound Attenuation—Convair 880/600. *Convair Traveler*, Apr., 1960, pp. 8, 9. Description of the acoustical blanketing used to cover the interior of the fuselage to prevent aerodynamic noise.

Input Impedances of Simple Cylindrical Structures. P. A. Franken. *ASA J.*, Apr., 1960, pp. 473–477. ONR-supported analysis, using the membrane theory, of the point impedance of a thin cylindrical shell driven at a frequency below the shell radial resonance. The study includes finite shells and rings, but does not take into account coupling to the external and internal media.

Aerodynamics, Fluid Mechanics

Aerothermochemistry, Dissociation, Ablation

Recent Advances in Chemical Kinetics of Homogeneous Reactions in Dissociated Air. W. G. Zinman. *ARS J.*, Mar., 1960, pp. 233–238. 50 refs. USAF-supported review of kinetic reactions in a boundary layer containing dissociated air. The three-body recombination mechanism is examined, and the recombination of iodine, oxygen, and nitrogen atoms is studied. Radiative recombination and bimolecular reactions are also considered, and an application of the theories is made to the study of flames.

Use of Reference Enthalpy in Specifying the Laminar Heat-Transfer Distribution Around Blunt Bodies in Dissociated Air. E. R. G. Eckert and O. E. Tewfik. *J. Aero/Space Sci.*, June, 1960, pp. 464–466. Application of the reference-enthalpy concept to Lee's method for predicting heat transfer around blunt bodies. Comparison is made with theory and with experimental results of Kemp, Rose, and Detra. Results show that Lee's method, modified by the reference-enthalpy concept, appears to predict closely the local heat-transfer coefficients along the surface of a blunt-nosed body in dissociated airflow.

Estimation of Nonequilibrium Reaction Flight Regimes for Blunt Bodies at Hypersonic Speeds. T. C. Adamson, Jr. *ARS J.*, Apr., 1960, pp. 358–360. USAF-supported presentation of an order of magnitude analysis where the characteristic time of reaction is compared to the characteristic residence time, with arbitrarily assigned limiting values of the ratios obtained. This type of study is useful in cases where the flow is very far from equilibrium, and in those cases where either catalytic or reaction poisoning surfaces are being considered.

Surface Recombination in the Frozen Compressible Flow of a Dissociated Diatomic Gas Past a Catalytic Flat Plate. P. M. Chung and A. D. Anderson. *ARS J.*, Mar., 1960, pp. 262–264.

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Stability & Control

An Axis System for Five and Six Degree of Freedom Airplane Dynamic Problems. W. L. Wynn. *J. Aero/Space Sci.*, June, 1960, pp. 473, 474. Presentation of a combination of (a) an earth-wind force-equation axis system and (b) a body moment-equation axis system to be used in dynamic problems of aircraft with five or six degrees of freedom.

Ustoichivost' Samoleta s Sokrashchennym Chislom Stepenei Svobody. T. Khaker. (*Stud. Cerc. Mec. Aplic.*, No. 3, 1959, pp. 655–661.) *Rev. Méc. Appl.*, No. 4, 1959, pp. 591–598. In Russian. Study covering the stability of aircraft in partially controlled flight. Several practical examples are presented to illustrate the applicability of the simplified method.

Power Spectral Analysis of Some Airplane Response Quantities Obtained During Operational Training Missions of a Fighter Airplane. H. A. Hamer and J. P. Mayer. *U.S., NASA TN D-366*, Mar., 1960. 41 pp. Presentation of power spectral densities of normal and transverse load factor and pitching acceleration for several types of missions normally performed by the airplane.

The Rolling Moments Due to Sideslip on High Tailplanes at Subsonic and Transonic Speeds. D. G. Mabey. *RAeS J.*, Mar., 1960, pp. 161–163. Presentation of experimental evidence to show that the rolling moment on a high tailplane varies roughly as the product of the fin and tailplane lifts.

The Longitudinal Frequency Response to Elevator of an Aircraft Over the Short Period Frequency Range. Appendix I—**Transfer Functions for the General Longitudinal Case.** Appendix II—**Range of Validity of the Approximate Values of the Short Period Stability Parameters B and C.** D. M. Ridland. *Gt. Brit., ARC CP 476* (Sept., 1959) 1960. 52 pp. BIS, New York, $1.35.

Wings & Airfoils

The Centre Section Shape of Swept Tapered Wings with a Linear Chordwise Load Distribution. J. C. Cooke. *Gt. Brit., ARC CP 470* (Sept., 1958) 1960. 28 pp. BIS, New York, $0.72.

Lift-Curve Slope and Induced Drag Factors of Large Aspect Ratio Straight-Tapered Wings. T. R. F. Nonweiler. *RAeS J.*, Apr., 1960, pp. 224, 225. Presentation of a simplified method of computing a solution to the Prandtl lifting line equation for large values of A/a_0, where A is the aspect ratio and a_0 is the sectional lift curve slope. An iterative method by which the nth approxi-

(*Continued on page 82*)

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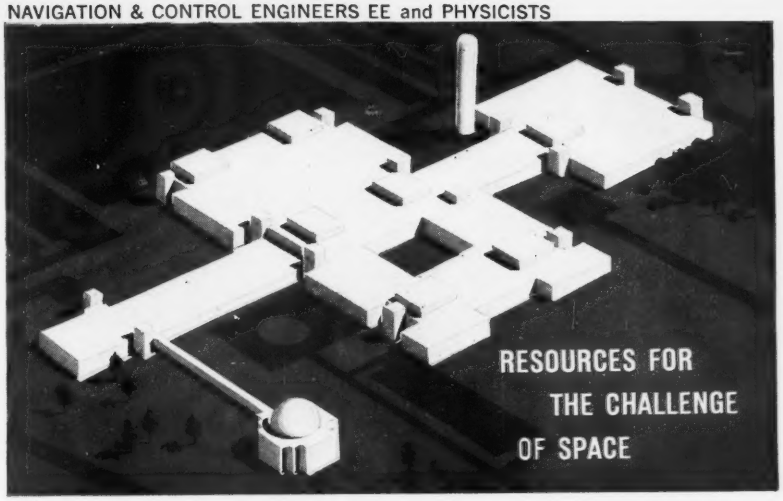

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INTERNATIONAL AERONAUTICAL ABSTRACTS

A Review of Worldwide Scientific and Technical Literature

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ACOUSTICS, SOUND, NOISE

SOUND EMISSION FROM JETS AT HIGH SUBSONIC VELOCITIES. Erik Mollð-Christensen and Roddam Narasimha. J. Fluid Mech., May, 1960, pp. 49-60. Presentation of measurements for the spectra of sound emission to the far field from jets at high subsonic velocities. The similarity relations found in the experiments suggest a mechanism of sound generation and scattering where the latter is of dominant importance. Such a possible mechanism is described.

ON THE AERODYNAMIC NOISE OF A JET. Appendix I - SUMMARY OF LINEARIZED ANALYSIS OF TWO-DIMENSIONAL OSCILLATIONS IN SHEAR LAYER. Appendix II - THE c_i-SPECTRUM AND THE PLANE WAVE APPROXIMATION. Sin-I Cheng. GASL TR 148 (AFOSR TN 59-1308), Apr., 1959. 56 pp. Presentation of a new model for analyzing the broad spectrum noise of a turbulent jet. The shear layer bounding the turbulent jet is assumed to play an important role in modifying the "quadrupole sound radiation" from the interior. To the sound emitting small scale turbulent eddies, the shear layer is laminar and is of an irregular contour, as if the large scale turbulent motions were frozen. The concept of "geometrical acoustics" is generalized to represent the passage of an acoustic ray through a laminar shear layer. This "generation" is visualized as the schematic representation, within the framework of geometrical acoustics, of the action of the Reynolds stress in transferring energy from the shear mean flow to the acoustic waves. In relating the quadrupole strength across the shear layer, those acoustic waves which become "stationary" with respect to the local mean flow somewhere in the interior of the shear layer, are significantly modified by the viscous action through the shear layer.

THE NOISE FIELD OF A SUBSONIC JET. Gino Moretti and Simon Slutsky. GASL TR 150 (AFOSR TN 59-1310), Nov., 1959. 165 pp. Study of the acoustic for field of a singularity under several different conditions of the medium. The simple cases of a source in an infinite wind, as observed at a fixed or moving point, are analyzed to permit comparison with physical systems of practical interest - e.g., jet engine fly-by noise analysis. Widespread misunderstanding of the Lighthill Mach number dependence is noted and clarified by means of the analysis. The far field of a singularity imbedded in a jet is determined as a function of jet velocity and temperature distribution with special emphasis on the case of uniform distribution in the jet. Comparison of experimental results is made and fair agreement noted.

AERODYNAMICS, FLUID MECHANICS

Aerothermochemistry, Dissociation, Ablation

HEAT AND MASS TRANSFER IN AERONAUTICAL ENGINEERING. D. B. Spalding. Aero. Quart., May, 1960, pp. 105-136. 23 refs. Study showing that standard techniques of heat and mass transfer theory, as practiced in other branches of engineering, can be applied to the corresponding aeronautical problems, particularly those arising in connection with high-speed flight and rocket propulsion. The first system represents the nose cone of a missile; here the problem is to predict the rate of heat transfer from the dissociated gases adjacent to the surface, and to assess the influences of transpiration cooling and of the so-called "ablation" of the heat shield. The boundary layer on the nose cone is laminar; the second system, by contrast, involves a turbulent boundary layer. The problem is the prediction of the heat transfer from the exhaust gases to the nozzle of a rocket engine. The mass transfer (erosion of the throat), which takes place when an uncooled graphite nozzle is used, is also discussed.

DISSOCIATIVE RELAXATION OF OXYGEN OVER AN ADIABATIC FLAT PLATE AT HYPERSONIC MACH NUMBERS. P. M. Chung and A. D. Anderson. US, NASA TN D-140, Apr., 1960. 28 pp. 20 refs. Application of the integral method to the study of the dissociative relaxation phenomena of pure oxygen over an adiabatic flat

plate at hypersonic Mach numbers. By means of the integral method, a solution is obtained to a problem involving finite rate dissociation and recombination in a hypersonic laminar boundary layer. It is found that dissociative equilibrium is never approximated over an adiabatic flat plate of reasonable length when the conditions of the free stream are those of the atmosphere at the altitude range from 50,000 to 200,000 ft. and Mach numbers from 10 to 20. It is predicted on the basis of the present analysis that heat transfer to a highly cooled flat plate may be quite closely approximated by the values of heat transfer across a chemically inert boundary layer with the same total energy per unit mass of the free-stream gas, at least for Mach numbers below 20 at the altitudes considered.

WAKE OF A SATELLITE TRAVERSING THE IONOSPHERE. S. Rand. Phys. Fluids, Mar.-Apr., 1960, pp. 265-273. Study of the structure of the wake behind a charged body moving supersonically through a low-density plasma. For the case of a body whose dimensions are considerably smaller than a Debye length, a solution is obtained which is very similar in structure to the solution obtained by using the linearized fluid dynamics equation. For the case of a disc whose radial dimensions are much larger than a Debye length, two conical regions are found in the wake. At the surface of each of these cones, for thicknesses of the order of a Debye length, the ion and electron densities are increased over their ambient values. Formulas for the electrohydrodynamic drag on a wire and on a large disc are obtained.

AN ANALYSIS OF NOSE ABLATION FOR BALLISTIC VEHICLES. Leonard Roberts. US, NASA TN D-254, Apr., 1960. 30 pp. Simplified analysis of the ablation experienced by ballistic vehicles. It is found, in general, that the heat lost by radiation is negligible compared with that disposed by ablation. A limiting total mass loss is found which is independent of vehicle weight and drag and independent of initial and impact velocity. Expressions are presented from which may be calculated the total mass loss experienced by the nose of the vehicle at both the stagnation point, where laminar flow prevails, and the sonic point, where the flow is considered turbulent. A typical calculation shows the change in shape of a hemispherical nose during re-entry.

OPLAVLENIE PLASTINY, OBTEKAEMOI SVERKHZVUKOVYM ILI VYSOKOTEMPERATURNYM GAZOVYM POTOKOM. A. B. Vatazhin. AN SSSR Otd. Tekh. Nauk Izv. Mekh. i Mashinostr., Nov.-Dec., 1959, pp. 7-13. In Russian. Study of the ablation of a semi-infinite plate in supersonic or high-temperature gas flow. The boundary layer formed along the plate is composed of two regions: (a) the region of flow of the plastic mass (liquid phase) and (b) the region of gas flow. The local friction coefficient, the temperature and velocity profiles, the velocity of flow along the separation line, and the amount of ablated mass are determined. The heat transfer equation is derived, assuming that a portion of the induced heat flux is transferred to the body, that the thickness of the plate is finite, and that the temperature over the lower surface of the plate is maintained constant. It is found that the velocity of propagation of the ablation front is reduced with the reduction in plate thickness, and it is shown that, by using Mangler's transformation, the solution can be applied to the flow around a circular cone.

OPLAVLENIE TEPLOPROVODIASHCHEI STENKI ZA DVIZHUSHCHIMSIA SKACHKOM UPLOTNENIIA. G. A. Tirskii. AN SSSR Dokl., Dec. 11, 1959, pp. 989-992. In Russian. Derivation of an exact solution for the problem of ablation of a flat wall, taking into account heat transfer to the wall in the region behind the shock wave, moving at constant speed in a gas at rest, parallel to the boundary of the wall. The equations of unsteady boundary layer in the gas and in the ablation layer which define the problem are derived, as are the equations of heat transfer in a solid body, under the assumption of laminar motion of gas and ablation. An exact solution is presented for the velocity and temperature profiles and for the laws of motion and normal velocities of the contact separation surface and the ablation surface.

HEAT PROTECTION BY ABLATION. R. M. Wood and R. J. Tagliani. Aero/Space Engrg., July, 1960, pp. 32-38, 45. Study of the desirable thermal and ablation properties of materials used for protecting load-carrying structures from excessive temperatures, and their interrelationship with the environment to which such protective coatings are subjected. The concepts of heat and temperatures of ablation are used together with other coating material properties for describing the effectiveness of different protective coatings in different thermal environments. The assumption of an equivalent square-wave heat-time input for any actual environment is discussed and justified for radically different environmental situations, including ICBM, Mars entry, anti-ICBM, manned entry, and nozzle applications. Using the square-wave heat input assumption, the unit coating weight required is presented as a function of intensity and duration of heating for several different protective coatings. The results are summarized by the graphical presentation of the relative weights required with a number of popular protection materials for different environmental situations, thereby emphasizing the need for different thermal properties with various environments.

Aerothermodynamics

A SIMPLIFIED THEORY OF SKIN FRICTION AND HEAT TRANSFER FOR A COMPRESSIBLE LAMINAR BOUNDARY LAYER. G. M. Lilley. Coll. of Aeronautics, Cranfield, Note No. 93, Jan., 1959. 76 pp. 31 refs. Presentation of approximate solutions of the laminar boundary layer equations for a perfect gas in steady flow at arbitrary external Mach number and wall temperature distribution. The method combines the use of the Stewartson-Illingworth transformation and application of Lighthill's method to yield the skin friction and rate of heat transfer. In addition, necessary

modifications are given for the separate cases of very low Prandtl number and for the flow near a separation point. Also given is Spalding's method for improving the accuracy of the wall value of shear stress and rate of heat transfer distributions along a wall having a nonuniform temperature distribution.

HEAT TRANSFER TO CYLINDERS IN CROSS-FLOW IN HYPERSONIC RAREFIED GAS STREAMS. R. N. Weltmann and P. W. Kuhns. US, NASA TN D-267, Mar., 1960. 24 pp. 16 refs. Presentation of heat-transfer studies for three rarefied gases of different molecular weight and accommodation coefficient. Tests were made at Mach numbers of about 5 with nitrogen, about 4 and 7 with helium, and about 6 with argon. Nusselt, Reynolds, and Knudsen numbers covered are $0.01 \leq Nu \leq 10$, $0.1 \leq Re \leq 1,000$, and $0.001 \leq Kn \leq 15$. The free-molecule flow data indicate an accommodation coefficient of about 0.9 for nitrogen, about 1.0 for argon, and about 0.4 for helium. Temperature-recovery ratios were also measured over a range of Knudsen numbers from free-molecule flow to almost continuum flow. For free-molecule flow the ratio approaches a value which is close to that predicted by theory.

STAGNATION-POINT HEAT-TRANSFER RATE MEASUREMENTS IN THE UNEXPANDED FLOW OF THE NPL HYPERSONIC SHOCK TUNNEL. B. D. Henshall. Gt. Brit., ARC CP 468, 1960. 10 pp. BIS, New York, $0.36. Investigation of the heat transfer rates to the stagnation points of 3/4-in. diam. glass spheres in shock tube flows for air with real gas stagnation temperatures up to 6,000°K. The experimental results show good agreement with those obtained at the NACA Langley Laboratory and the AVCO Research Laboratory. The experimental results average 22% lower than the theoretical values predicted by Fay and Riddell.

HEAT AND MASS TRANSFER FOR FLOW PAST AN ARBITRARY CYLINDER. Appendix A - THE EXACT SOLUTION FOR WEDGE FLOWS. Appendix B - THE MANGLER TRANSFORMATION. Appendix C - ALTERNATIVE FORMULATIONS OF THE ENERGY EQUATION. P. B. Scott. MIT NSL TR 383 (AFOSR TN 59-1268), Sept., 1959. 87 pp. 29 refs. Presentation of a method to determine the heat transfer to a cylinder undergoing foreign gas injection, and specifically that injection distribution corresponding to an isothermal wall. A step-by-step solution is obtained by matching the boundary-layer flow at any station of a cylinder to the flow at a corresponding station on an equivalent wedge. The necessary parameters are derived by consideration of the boundary-layer equations. The matching criteria are presented and two methods of solution (graphical and numerical) are described. The necessary set of wedge flow solutions is obtained for various wedge apex angles and helium injection.

Boundary Layer

FORCED MIXING IN BOUNDARY LAYERS. G. B. Schubauer and W. G. Spangenberg. J. Fluid Mech., May, 1960, pp. 10-32. 19 refs. Navy-sponsored investigation of the effect of increasing the rate of mixing in turbulent boundary layers in a region of adverse pressure gradient. Only the two-dimensional case is considered, and the speeds are low enough to neglect compressibility. A variety of mixing schemes was tried, which differed considerably in effectiveness, but had a generally similar effect on the flow. Except for effects arising from changes in displacement and momentum thickness introduced at the devices, their effect on the layer was basically equivalent to that of a decrease in pressure gradient. Apart from forced mixing, the shape of the pressure distribution was found to have a significant effect on displacement and momentum thickness, these being minimized and the wall distance decreased for a given pressure rise by a distribution with an initially steep and progressively decreasing gradient.

SOME EFFECTS OF SHOCK-INDUCED SEPARATION OF TURBULENT BOUNDARY LAYERS IN TRANSONIC FLOW PAST AEROFOILS. H. H. Pearcey. Gt. Brit., ARC R&M 3108, 1959. 61 pp. 27 refs. BIS, New York, $3.78. Discussion of the physical nature of the overall flow and the mechanism by which separation affects its developement. Separation at the shock on the upper surface is first shown to cause a slowing up of the rearward movement of this shock with respect to the variation of trailing-edge pressure. The concept is then introduced that the steady flow for each free-stream Mach number has to be such that the trailing-edge pressure can satisfy two conditions: (a) an approximate equality between the pressures on two sides of the wake, and (b) a compatibility with the free-stream static pressure. It is suggested that the former condition largely determines the relative rates of shock movement (or flow development) on the two surfaces, and the latter determines the actual rates with respect to free-stream Mach number.

BRIEF EXPERIMENTS ON A FLAPPED AEROFOIL HAVING A CUSPED CAVITY AND A BLOWING JET AT THE CUSP. A. D. Wood. Canada, NRC Aero. Rep. LR-269, Dec., 1959. 19 pp. Investigation on a simple flapped airfoil incorporating a cusped cavity and having a blowing jet at the cusp. The results show that it is possible to produce a flow regime in which the cavity is occupied by a stable trapped vortex. With the airfoil immersed in a quasi-two-dimensional finite stream, greater rotation of the resultant force vector was obtained with a flap of this type than with a flap having no cavity. The results indicate that the combination of a blowing jet and a trapped vortex may be used to advantage in enabling an external flow to overcome an adverse pressure gradient.

THE BOUNDARY-LAYER TRANSITION CHARACTERISTICS OF TWO BODIES OF REVOLUTION, A FLAT PLATE, AND AN UNSWEPT WING IN A LOW-TURBULENCE WIND TUNNEL. F. W. Boltz, G. C. Kenyon, and C. Q. Allen. US, NASA TN D-309, Apr., 1960. 45 pp. Investigation showing

that the transition Reynolds number characteristics of the several models exhibited similar adverse (forward movement of transition) effects of increasing tunnel air speed in the low subsonic speed range. The pressure distribution was a primary factor in determining the level of transition Reynolds number. At low speed, however, transition Reynolds number decreased with increasing air speed or Mach number, although there were essentially no changes in the pressure distributions. It was concluded that these reductions in transition Reynolds number could be attributed to either increased air-stream turbulence or to changes in the frequency and/or intensity of sound waves with increasing air speed.

THE DEVELOPMENT OF TURBULENT BOUNDARY LAYERS WITH NEGLIGIBLE WALL STRESS. A. A. Townsend. J. Fluid Mech., May, 1960, pp. 143-155. Presentation of an alternative theory to that of Stratford, using the same two assumptions, but leading to the elimination of some inconsistencies in the original theory and to a better description of some of the experimental results. The first assumption is that the flow in the outer part of the layer is affected only by the original Reynolds stresses during the initial development, and the second is that flow in the equilibrium layer close to the wall is determined by the pressure gradient and is independent of upstream conditions. The principal results are the following: (1) a criterion for zero wall stress in an adverse pressure gradient of sufficient strength, (2) the form of the pressure distribution for a self-preserving flow with zero stress, (3) the mean velocity distribution in this flow, and (4) an estimate of the constant in the "square root" velocity distribution for flow near a wall with zero stress.

DISTRIBUTIONS OF VELOCITY, ENTHALPY AND SHEAR STRESS IN THE COMPRESSIBLE TURBULENT BOUNDARY LAYER ON A FLAT PLATE. D. A. Spence. Gt. Brit., RAE Rep. Aero. 2631, Nov., 1959. 31 pp. 15 refs. Study of a set of velocity profiles measured in turbulent boundary layers in a zero pressure gradient at Mach numbers between 5 and 8 by Lobb, Winkler, and Persh. The properties of the velocity profile are used as the physical starting point for a unified account of the boundary layer in a zero pressure gradient. They are shown to be consistent with the intermediate enthalpy method for correlating compressible and incompressible values of the skin friction. By substitution in the equation of motion, expressions are found for the distribution of shear stress in the inner and outer regions. A relation between the distributions of enthalpy and velocity is then found from the energy equation, using the concept of a turbulent Prandtl number α, constant across the layer, to relate eddy conductivity to eddy viscosity. The final expression is similar in form to Crocco's integral for the laminar boundary layer, and is evaluated using a velocity-shear relation found earlier. An expression which agrees well with available experimental data is found for the heat transfer coefficient as a function of recovery factor and skin friction coefficient.

ON SURFACE PRESSURE FLUCTUATIONS IN TURBULENT BOUNDARY LAYERS. Appendix A - THE PRESSURE EQUATION FOR THE WALL JET. Appendix B - THE EVALUATION OF AN INTEGRAL. Appendix C - THE STRUCTURE OF THE LARGE EDDIES NEAR THE WALL IN A TURBULENT BOUNDARY LAYER. Appendix D - ON SPACE-TIME CORRELATIONS OF THE FLUCTUATING VELOCITY AND PRESSURE. Appendix E - THE EVALUATION OF THE PRESSURE SPECTRUM. G. M. Lilley and T. H. Hodgson. Coll. of Aeronautics, Cranfield, Note No. 101, Apr., 1960. 51 pp. 24 refs. Review of existing work on the pressure fluctuations in turbulent shear flow with reference to the problem of wall turbulence. An approximate theory for the pressure fluctuations on the wall under both a turbulent boundary layer and a wall jet is given and indicates in the latter case an intensity many times that corresponding to the flow over a flat plate at zero pressure gradient, as typified by measurements on the wall of a wind tunnel. Experiments on a wall jet confirm these predictions and suggest that the intensity of the pressure fluctuations in the regions of adverse pressure gradient, on wings and bodies approaching and beyond separation, will be higher than in regions of zero pressure gradient. Appendices are included which deal with the necessary extensions to the analysis to fit the velocity correlation functions as measured by Grant - i.e., the effects of time delay and eddy convection.

Flow of Fluids

EXACT SOLUTIONS FOR THE ONE-DIMENSIONAL VISCOUS FLOW OF A PERFECT GAS. Gerald Rosen. Phys. Fluids, Mar.-Apr., 1960, pp. 191-196. ONR-sponsored derivation of velocity-free equations for the unsteady one-dimensional real fluid flow of a perfect gas. The study of admissible symmetries facilitates the integration of partial differential equations. These equations admit a pressure-time symmetry, a stress symmetry, and a displacement symmetry. Fundamental solutions associated with each of the three symmetries are given.

ENTROPY PRODUCTION AND PRESSURE WAVES. Gerald Rosen. Phys. Fluids, Mar.-Apr., 1960, pp. 188-190. ONR-sponsored derivation of the velocity-free equations of one-dimensional flow neglecting thermal conduction and viscous dissipation. The strength of finite amplitude pressure waves is introduced into the theory. This quantity is conserved if the entropy of each fluid particle remains constant with time. The growth or decay of the strength is examined for a perfect gas which produces entropy.

EXPERIMENTAL INVESTIGATION AT A MACH NUMBER OF 3.11 OF THE LIFT, DRAG, AND PITCHING-MOMENT CHARACTERISTICS OF FIVE BLUNT LIFTING BODIES. William Letko. US, NASA TN D-226, Apr., 1960. 13 pp. Presentation of test results showing that all the bodies were statically unstable about the geometric center of the bodies, except one which was neutrally

stable. These results indicate that Newtonian theory might be applied to estimate the drag at zero angle of attack and the pitching-moment-curve slope. Indications are, however, that Newtonian considerations would not apply for estimating the normal force of bodies of the type tested at the Mach number of the tests.

LOCAL HEAT TRANSFER AND RECOVERY TEMPERATURES ON A YAWED CYLINDER AT A MACH NUMBER OF 4.15 AND HIGH REYNOLDS NUMBERS. Appendix A - TURBULENT BOUNDARY-LAYER THEORY ON YAWED INFINITE CYLINDERS. Appendix B - HEAT TRANSFER IN THE LAMINAR BOUNDARY LAYER ON YAWED INFINITE CYLINDERS. I. E. Beckwith and J. J. Gallagher. US, NASA Memo. 2-27-59L, Apr., 1959. 59 pp. 26 refs. Measurements of local heat transfer, equilibrium temperatures, and wall static pressures on a cylinder at yaw angles of 0°, 10°, 20°, 40°, and 60°. Increasing the yaw angle from 0° to 40° increased the stagnation-line heat-transfer coefficients by 100% to 180%. A further increase in yaw angle to 60° caused a 40% decrease in heat-transfer coefficients. At zero yaw angle, the boundary layer over the entire front half of the cylinder was laminar, but at yaw angles of 40° and 60° it was evidently completely turbulent, including the stagnation line, as determined by comparison of local heat-transfer coefficients with theoretical predictions. The level of heating rates and the nature of the chordwise distribution of heat transfer indicates that a flow mechanism different from the conventional transitional boundary layer may have existed at the intermediate yaw angles of 10° and 20°. The average heat-transfer coefficients over the front half of the cylinder are in agreement with previous data over a comparable Reynolds number range.

THE OSCILLATING PLATE IN MAGNETOHYDRODYNAMICS. J. A. Steketee. UTIA Rep. 63, Aug., 1959. 36 pp. Extension of the problem of the oscillating plane in a viscous incompressible fluid to the case of conducting fluid with a magnetic field perpendicular to the plane. In the problem appear two penetrating depths which depend on the intensity of the applied magnetic field; if the two penetration depths are unequal when the magnetic field is absent, the effect of switching on the field is an increase in the larger penetration depth and a decrease of the smaller. Explicit results are given for the case of equal viscous and magnetic Reynolds number. The analysis suggests that boundary-layer thicknesses in magnetohydrodynamics will depend on the magnetic field intensity.

COMPRESSIBILITY EFFECTS IN MAGNETO-AERODYNAMIC FLOWS PAST THIN BODIES. J. E. McCune and E. L. Resler, Jr. J. Aero/Space Sci., July, 1960, pp. 493-503. 10 refs. Development of procedures for the solution of a class of magnetohydrodynamic problems over the entire Mach number range and for all ratios of magnetic to fluid-dynamic pressure. The results obtained are analogous either to the Ackeret theory or the Prandtl-Glauert rule of conventional aerodynamics, depending on the relative values of the flow speed and the appropriate speed of propagation of magnetoacoustic disturbances. The methods used and the physical interpretation of the solutions obtained vary according to the orientation of the magnetic field with respect to the flow direction.

STOKES FLOW OF AN ELECTRICALLY CONDUCTING FLUID IN A UNIFORM MAGNETIC FIELD. Kanefusa Gotoh. Phys. Soc. Japan J., Apr., 1960, pp. 696-705. Study of a general theory applicable to three-dimensional flow. It is found that the neutrality of the electric charge density does not hold exactly when the undisturbed magnetic field is not perpendicular to the vorticity vector. It is also found that the vorticity and the electric current density are confined in paraboloidal region, thus making a "wake" which extends in the direction of the undisturbed magnetic field. Distribution of the electric charge density also shows the same structure. The flow past a sphere is investigated as an example. The drag is obtained in a power series of the Hartmann number M. The component of the drag perpendicular to the undisturbed magnetic line of force is found to be larger than its parallel component. It is shown for the three-dimensional cases that the velocity field includes components which express the two-dimensional irrotational flow.

AXIALLY SYMMETRIC STAGNATION-POINT FLOW OF AN ELECTRICALLY CONDUCTING FLUID UNDER TRANSVERSE MAGNETIC FIELD. Tsunehiko Kakutani. Phys. Soc. Japan J., Apr., 1960, pp. 688-695. Analysis of axially symmetric stagnation-point flow of an incompressible, viscous, and electrically conducting fluid in the presence of a transverse uniform magnetic field with small magnetic Reynolds numbers. The velocity field is dependent on the asymptotic field far from the wall, and the shear stress on the wall is given in terms of the intensity of the field, being characterized by the parameter β. The flow of this type may be considered as a simple model for that around the nose of a body of revolution moving through an ionized atmosphere at hypersonic speed. In this context, it is convenient to use Bush's results for estimating β. The ratio of the shear stresses with and without the magnetic field is calculated and shown graphically as a function of N (where $N = SR_m$, S being the pressure number and R_m the magnetic Reynolds number.) It is found that the shear stress at the wall is considerably reduced by the hydromagnetic interactions.

STEADY LONGITUDINAL MOTION OF A CYLINDER IN A CONDUCTING FLUID. Hidenori Hasimoto. J. Fluid Mech., May, 1960, pp. 61-81. 17 refs. Analysis considering the motion of a cylinder in a conducting fluid with the presence of a uniform magnetic field. Due to Alfvén waves originating at the cylinder, two opposite "wakes" parallel to the applied magnetic field are found. A formula which relates the total drag on the cylinder to the electric potential difference $\delta\theta$ be-

tween the two undisturbed regions outside these two wakes is derived. The reduction to a classical boundary-value problem is made for the case of an insulating cylinder. Exact solutions are obtained for the case of a perfectly conducting or an insulating flat strip of semi-infinite width. These give a clear picture of the fields, especially in the transition region near the edge of the strip. The case of a strip of finite width is also discussed with special reference to the viscous and the magnetic drags, D_f and D_m.

ON THE MOTION OF A NON-CONDUCTING BODY THROUGH A PERFECTLY CONDUCTING FLUID. K. Stewartson. J. Fluid Mech., May, 1960, pp. 82-96. Analysis considering the motion of bodies in a direction parallel to an applied magnetic field and through a perfectly conducting fluid. It is shown that the perturbation in the state of the fluid cannot remain small except in the particular case when the velocity U of the body is much smaller than that of the Alfvén waves in the fluid. In this case, however, the perturbation is not confined to the neighborhood of the body, and extends to infinity inside planes which touch the body and are parallel to the undisturbed magnetic field. In addition, the body experiences a drag.

THE BLUNT BODY VISCOUS LAYER PROBLEM WITH AND WITHOUT AN APPLIED MAGNETIC FIELD. Hakuro Oguchi. Brown U. Div. Eng. Rep. (USAF WADD TN 60-57), Feb., 1960. 45 pp. Presentation of a new approach to the viscous layer problem both with and without an applied magnetic field. According to this method, solutions can be found in closed analytic form so that numerical integrations associated with a two-point boundary value problem are avoided. Solutions are presented to the first order in ϵ, the ratio of the density ahead of, to that behind, the shock wave. In the nonmagnetic case, numerical results for both the shock wave detachment distance and skin friction are presented for a value of $\epsilon = 0.1$ and they are shown to be in good agreement with the numerical calculations of Probstein and Kemp, at least when the Reynolds number is not too large. Numerical results are also presented on the effect of an applied magnetic field on both the shock wave detachment distance and skin friction. It is found that for a fixed value of ϵ and Reynolds number the skin friction decreases and the detachment distance increases for increasing values of the magnetic field parameter S, which is proportional to the magnetic pressure divided by the total pressure.

STABILITY OF PARALLEL FLOW IN A PARALLEL MAGNETIC FIELD AT SMALL MAGNETIC REYNOLDS NUMBERS. P. G. Drazin. J. Fluid Mech., May, 1960, pp. 130-142. 13 refs. Navy-sponsored analysis considering the hydromagnetic stability for the flow of an incompressible conducting fluid, using the Orr-Sommerfeld equation for an electrically conducting fluid. It is shown that any given small wave disturbance can be stabilized by a sufficiently strong magnetic field if the Reynolds number is finite and the magnetic Reynolds number small. Stability of velocity profiles with a point of inflection at small magnetic Reynolds number and infinite Reynolds number is considered in detail. Perturbation methods are developed to find stability characteristics in two cases, (a) when the magnetic field is weak, and (b) when the disturbance is a long wave. These methods are applied to the jet and the half-jet, which are both found to be unstable to long-wave disturbances, however strong the magnetic field. An analysis of the jet reveals that the magnetic field makes inviscid long-wave disturbances more unstable.

THE OSCILLATING PLATE PROBLEM IN MAGNETOHYDRODYNAMICS. W. I. Axford. J. Fluid Mech., May, 1960, pp. 97-102. Analysis of the oscillating plate problem for the case of an incompressible, electrically conducting fluid in the presence of a magnetic field. The boundary conditions are examined in detail, and a solution is found with the aid of suitable approximations. The motion of the fluid is shown to consist mainly of magnetohydrodynamic waves, but there is also a viscous boundary layer in which the solution agrees with that derived earlier.

STUDIES ON MAGNETO-HYDRODYNAMIC WAVES AND OTHER ANISOTROPIC WAVE MOTIONS. Appendix A - VELOCITY OF ENERGY PROPAGATION FOR A PLANE WAVE IN AN ANISOTROPIC MEDIUM. Appendix B - APPLICATION OF THE METHODS OF THIS PAPER TO PROBLEMS WITH ZERO INITIAL CONDITIONS. M. J. Lighthill. Royal Soc. (London) Philos. Trans., Ser. A, Mar. 31, 1960. 34 pp. 13 refs. Application of a method for asymptotically evaluating Fourier integrals to investigate linear partial differential equations with constant coefficients, but which may be of any order and represent wave motions that are anisotropic or dispersive, or both. The method gives the asymptotic behavior (at large distances) of solutions of these equations, representing waves generated by a source of finite or infinitesimal spatial extent. Emphasis is placed on sources of fixed frequency and solutions satisfying the radiation condition. The mathematical results are given a partial physical interpretation by arguments determining the velocity of energy propagation in a plane wave traversing an anisotropic medium. These show that even for nondispersive (elastic) waves, the energy propagation velocity is not in general normal to the wave fronts, although its component normal to them is the phase velocity. In addition, the effects of a noncollisional nature, which are neglected in the simple theory, are considered; particularly compressibility and Hall current, which would alter the unidirectional, attenuationless propagation of the waves.

RELAXATION HEATING OF A PLASMA BY SURFACE INTERACTION WITH A MAGNETIC FIELD. R. P. Treat. Plasmadyne Corp. TN T-3TN109-335 (AFOSR TN 59-1151), Oct. 15, 1959. 37 pp. Investigation of the heating of a fully ionized deuterium plasma by collisional relaxation for temperatures of the order of one kev. The

model used for the study consists of a long cylindrical plasma column confined and manipulated by an axial magnetic field that is induced by currents flowing in a one-turn coil surrounding the plasma. Conditions are such that the field is excluded from the interior of the plasma - the interaction between the plasma and field is essentially a surface phenomenon. To determine, in order of magnitude, the amount of heating due to collisional relaxation effects, several ideal cycles are studied. These cycles consist of a two-dimensional adiabatic compression from 0 to 1, relaxation to equipartition from 1 to 2, two-dimensional adiabatic expansion from 2 to 3, and a final relaxation from 3 to 4. The results giving the energy increase for one cycle and the energy increase for m cycles, show that the heating is large enough to warrant study of more realistic cycles.

DER EINFLUSS EBENER KÖRPER AUF STROMAUFWÄRTS LIEGENDE SENKRECHTE STÖSSE. Dietrich Rues. ZFW, Mar., 1960, pp. 67-76. In German. Investigation of the influence of two-dimensional bodies on normal stationary shocks, calculated under the assumption of small perturbations. Numerical examples are presented for the case of a flat plate at incidence and that of a parabolic biconvex airfoil. An approximate method is developed for symmetrical profiles, and a comparison is made with earlier results.

BERECHNUNG VON KUGELSYMMETRISCHEN VERDICHTUNGSSTÖSSEN MITTELS CHARAKTERISTIKENVERFAHREN. F. Bartlmä. DVL Bericht No. 103, Dec., 1959. 34 pp. Westdeutscher Verlag, Köln & Opladen. In German. Application of the method of characteristics for an isentropic gas to calculate spherical shock waves converging toward the center where they are reflected. The effect of the wavelength and shock strength of the initial sawtooth wave is studied, and the validity of Guderley's solution for strong spherical shocks in the neighborhood of the center is examined. The accuracy of the applied method of characteristics is verified by means of conservation laws, and a comparison is made with the results obtained by Schmidt.

ON THE ONE-DIMENSIONAL OVERTAKING OF A SHOCK WAVE BY A RAREFACTION WAVE. Appendix A - DERIVATION OF EQUATIONS FOR THE FOUR WAVE SYSTEMS. Appendix B - THE CRITICAL PRESSURE RATIO EQUATION. I. I. Glass, L. E. Heuckroth, and S. Molder. UTIA TN 30, July, 1959. 30 pp. Navy-sponsored presentation of solutions in a closed form for the overtaking of a shock wave by a rarefaction wave in a perfect inviscid gas. The equations are solved numerically on a digital computer in terms of initial pressure ratios across the shock and rarefaction waves in the range of 1 to 1,000, and for specific heat ratios in the range of 1 to 5/3. The results are presented graphically. It is shown that four basic wave systems can result after interaction: (a) a transmitted shock and a reflected rarefaction wave, (b) a transmitted shock and a reflected compression wave that steepens into a shock wave, (c) a transmitted rarefaction wave and a reflected rarefaction wave, and (d) a transmitted rarefaction wave and a reflected compression wave that steepens into a shock wave. In all cases the transmitted and reflected waves are separated by a region of variable entropy or contact region. Limiting cases exist where either the reflected or transmitted wave or both simultaneously can be Mach waves. It is shown that for a monatomic gas and for a gas with a specific heat ratio of unity some of the wave systems do not exist.

A THEORY OF DECAYING HOMOGENEOUS TURBULENCE. R. G. Deissler. Phys. Fluids, Mar.-Apr., 1960, pp. 176-187. 11 refs. Derivation of an equation containing quadruple and quintuple correlations by considering correlations between fluctuating quantities at four points in a turbulent fluid. The equation is made determinate by neglecting the higher-order (quintuple) correlations. The combining of this equation with the two- and three-point correlation equations, and assuming a particular set of initial conditions, results in a solution which appears to represent the turbulence for times between the initial and final periods.

Internal Flow

EXPERIMENTAL INVESTIGATION OF THE STALLED FLOW OF A SINGLE-STAGE AXIAL FLOW COMPRESSOR. M. D. Wood, J. H. Horlock, and E. K. Armstrong. Aero. Quart., May, 1960, pp. 159-170. Study showing that variation of axial spacing between neighboring blade rows can alter the stall characteristics of a compressor stage. The stall cell patterns of this compressor stage are described in detail, and changes of slope in stage temperature and pressure rise characteristics are explained in terms of stall propagation. Strain gage tests on stator blades are used to indicate the possibility of large dynamic stresses occurring when the stall cell frequency is equal to the blade natural bending frequency.

AERODYNAMIC INSTABILITY OF SUPERSONIC INLET DIFFUSERS. Chieh-Chien Chang and Cheng-Ting Hsu. ARS J., May, 1960, pp. 468-475. 16 refs. USAF-sponsored analysis showing that the stability problem can be reduced to finding the acoustic impedance at the inlet of the plenum chamber. This is obtained by solving the linearized viscous compressible flow equations in the entire subsonic diffusion regimes with assumptions of one-dimensional quasi-steady flow and linear velocity distribution. It is found that the self-excited shock oscillation is not possible in the absence of viscous dissipation. Flow instability is found to be due to further entropy generated by viscous dissipation in addition to shock oscillation. Neutral stability boundaries are obtained in terms of the ratio of perturbation entropy to the corresponding shock velocity and are in agreement with Stoolman's experimental data. The present analysis confirms Trimpi's theory of instability and

also justifies the Sterbentz-Evvard theory in the range of "steady" subcritical operation.

OPERATIONAL METHOD OF DETERMINING INITIAL CONTOUR OF AND PRESSURE FIELD ABOUT A SUPERSONIC JET. G. W. Englert. US, NASA TN D-279, Apr., 1960. 37 pp. 14 refs. Presentation of simple expressions for estimating the initial contour of a jet exhausting into a supersonic stream and into quiescent surroundings. These expressions are obtained by using a modified Laplace transform to solve the linearized potential flow equation. The initial slope of the jet boundary is kept as a parameter in the final expressions, which permits a study of the use of an exact, in place of a linearized, initial value. Results are compared with characteristics solutions and experimental data. An expression is also developed to determine the pressure field of a supersonic stream surrounding the jet. This expression is applied to determine the pressure influence of the jet on a nearby flat plate. These results are also compared with experimental data.

THE IMPLICATIONS OF ISENTROPIC NOZZLE FLOW FOR A PERFECT GAS. Ch. P. Costello and W. B. Nordqist. Trend in Eng., Apr., 1960, pp. 23-27. Analysis of a frictionless adiabatic flow of a perfect gas in a nozzle to determine exact relations among the thermodynamic properties of the flowing fluid. It is found that the relations commonly employed in classical thermodynamics are valid, although the relations are based on an equation not strictly applicable to the case analyzed. The study shows that there is one single nozzle design to provide true frictionless, adiabatic flow rather than a family of nozzles as is implied by standard works on the subject. An approach is given for obtaining the relations among properties that must hold for flow of fluids, even for those that cannot be considered perfect gases.

A STUDY OF EQUILIBRIUM REAL-GAS EFFECTS IN HYPERSONIC AIR NOZZLES, INCLUDING CHARTS OF THERMODYNAMIC PROPERTIES FOR EQUILIBRIUM AIR. Appendix - EXTENSION OF CHARTS OF THERMODYNAMIC PROPERTIES FOR AIR. W. D. Erickson and H. S. Creekmore. US, NASA TN D-231, Apr., 1960. 179 pp. 10 refs. Presentation of flow parameters in tabular form, calculated for air as a real gas in chemical equilibrium for a series of stagnation temperatures between 2, 790°R. and 4, 950°R. and pressures up to 1, 000 atm. From these charts, it is possible to calibrate a hypersonic nozzle in the conventional way. A method is shown for calculating an inviscid nozzle contour including real-gas effects. Charts of thermodynamic properties for air from which these calculations were made and from which additional calculations may be made are included. Also presented is the limiting Mach number for condensation as a function of stagnation temperature and pressure.

ISOTHERME DÜSENSTRÖMUNGEN. V. Stingelin. Astronautica Acta, Fasc. 1, 1960, pp. 61-74. In German. Analysis considering the possibility of generating high velocities by means of isothermal expansion. The following cases are treated: constant difference between wall temperature and average gas temperature, and constant wall temperature with given heat production along the axis. The influence of friction and the temperature boundary layer is considered and, for the turbulent heat transfer, the Reynolds analogy is applied.

Wings & Airfoils

THEORY OF WINGS IN SLIPSTREAMS. Appendix A - PROOF THAT WING PLUS SLIPSTREAM CAN BE REPRESENTED BY DISTRIBUTION OF DOUBLETS OVER WING-WAKE AND SLIPSTREAM SURFACES. Appendix B - DERIVATION OF THE PAIR OF SIMULTANEOUS INTEGRO-DIFFERENTIAL EQUATIONS. H. S. Ribner. UTIA Rep. 60, May, 1959. 28 pp. 16 refs. Development of a potential theory for the aerodynamics of a wing in one or more slipstreams of arbitrary shape or position. The central idea, involving the use of a "reduced" potential within the slipstream jet, is representation of the flow by means of two distributions of vortices or doublets: one over the wing and its wake, and the other over the jet boundary. A pair of simultaneous integral equations are developed for their determination. The integrals are reduced to one dimension, then specialized to a circular jet, and approximated as summations.

HIGH SPEED WIND TUNNEL TESTS ON A STRAIGHT WING HAVING AERODYNAMIC SWEEP. H. G. Darling and R. J. Sandeman. Australia, ARL Rep. A.116, Aug., 1959. 43 pp. Investigation of a method of Poole and Stephens for obtaining aerodynamic sweep on a straight wing by suitable choice of spanwise variation in section profile. At low speeds, the lowest pressure isobar was swept alternately backward and forward across the span at a mean angle of 36°. To determine the high speed characteristics of this wing, pressure distributions and strain gage force measurements were obtained at Mach numbers up to 0.95. From the pressure distributions it is apparent that the isobars are unswept near the surface discontinuities at all speeds. With increases in speed up to the critical, there is a progressive reduction in the angle of sweep of the isobars. Beyond the critical speed, a change in the form of the section pressure distributions greatly reduced the sweep of the isobars immediately upstream of the pressure recovery region. The force measurement showed that there was no significant improvement in the drag rise characteristics of this wing when compared with an equivalent wing having unswept isobars.

THE TRANSONIC CHARACTERISTICS OF A FAMILY OF TWO-DIMENSIONAL SYMMETRICAL DOUBLE WEDGE PROFILES. I - DETAILS OF THE PROGRAMME AND THE ZERO-LIFT RESULTS. II - RESULTS OBTAINED FOR LIFTING PROFILES. R. J. Sandeman. Australia, ARL Rep. A.114; Rep. A.115, Aug., 1959. 98; 90 pp. 35

refs. Investigation of four double wedge profiles over a Mach number range from 0.4 to 1.14 and an incidence range of 0° to 4°. The following data are obtained for natural and fixed boundary-layer transition of zero-lift and lift profiles: (1) static pressure distributions, (2) C_L, C_M, and C_D from strain gage force measurements, and (3) shadowgraph observations of the flow behavior. Comparison is made with theoretical solutions and reasonable agreement is found.

PRESSURE DISTRIBUTION ON SYMMETRICAL WING SECTIONS AT NEAR SONIC SPEEDS. J. Rotta. (Aerody. Versuchsanstalt, Göttingen, Bericht No. 59-A-36, Sept., 1959.) Gt. Brit., RAE Lib. Transl. 876, Feb., 1960. 21 pp. 15 refs. Presentation of an approximate method based on the experimental observation that the pressure distribution in front and behind the shock wave remains approximately constant for Mach numbers within a defined range. The method of Spreiter and Alksne is used to determine the shape of the pressure distribution in front and behind the shock wave. This method reduces the nonlinear potential equation of near-sonic flow to a linear partial differential equation of the parabolic type. The position of the shock wave is determined so that the drag found as the sum of pressure components in the direction of the stream is equal to the drag which results from changes of the entropy through the shock wave. Calculations are carried out for the symmetrical circular arc section and the results are compared with those obtained by other methods and experimentally.

SOME CALCULATIONS OF SHAPE, PRESSURE DISTRIBUTION AND DRAG DUE TO LIFT FOR A "MILD OGEE" WING WITH PRESCRIBED CENTRE OF PRESSURE POSITION. Appendix - EVALUATION OF WAVE DRAG DUE TO LIFT. A. L. Courtney. Gt. Brit., RAE TN Aero.2655, Oct., 1959. 27 pp. Discussion of the design of slender wings, emphasizing the properties of plan forms with streamwise tips and "low" values of the Collingbourne plan-form parameter p - i.e., "high" values of the aspect ratio for a given slenderness ratio. In this context a low value of p means a value of about 0.5 or less, corresponding to an ogee type plan form, as compared with 0.667 for the parabolic gothic. It has been shown that for plan forms of $p = 0.5$ or less it is difficult to avoid adverse pressure gradients associated with the inflection in the leading-edge shape. Calculations are made for a "mild ogee" plan form having a $p = 0.533$, a Newby area distribution, rhombic transverse thickness distributions, and various streamwise and spanwise downwash distributions. The calculations include the shape of the camber surface, upper-surface distributions, load distributions, and drag due to lift. An important feature of the calculation procedure is that the camber shapes are all chosen to produce a given center of pressure position according to slender-wing theory, and details are included of the method used for meeting this condition while retaining some control over wing shape, pressure distribution, and drag due to lift.

EXTENSION OF EVVARD'S METHOD TO OSCILLATORY SUPERSONIC FLOW. Harry Ferguson and K. G. Guderley. ZFW, Mar., 1960, pp. 76-86. Presentation of a method which is sufficiently simple to be used as the basis for numerical analysis. The computation of the pressure distribution on a thin wing oscillating in supersonic flow leads to a Volterra integral equation of the first kind with a singular kernel. Exact solutions in the form of an integral exist for steady supersonic flow with an angle of attack, and for oscillatory flows with only supersonic leading edges. On the basis of these exact solutions, a hypothesis is made that transforms the original equation into a Volterra integral equation of the second kind with a fairly simple kernel. This equation is much more tractable than the original equation; for the known cases the kernel is identically equal to zero.

INVESTIGATION OF AERODYNAMIC EFFECTS OF EXTERNAL COMBUSTION BELOW FLAT-PLATE MODEL IN 10- BY 10-FOOT WIND TUNNEL AT MACH 2.4. R. G. Dorsch, Harrison Allen, Jr., and Murray Dryer. US, NASA TN D-282, Apr., 1960. 25 pp. Study in which heat is added directly to the supersonic air stream by external combustion of aluminum borohydride. Lift forces of 55 to 60 lbs. per sq. ft. are generated over the first foot of chord of the model at a static temperature of 259°R. and a pressure altitude of 62,000 ft. The pressure data are compared with previously reported small-tunnel results in order to obtain an appraisal of possible tunnel effects encountered in the small-tunnel tests. Good agreement was obtained for the shorter-chord small-tunnel models, but the longer-chord small-tunnel models are found to have spurious pressure increases at large distances downstream from the fuel orifices.

SOME NOTES ON THE ZERO-LIFT WAVE DRAG OF SLENDER WINGS WITH UNSWEPT TRAILING EDGE. J. Weber. Gt. Brit., RAE Rep. Aero.2630, Dec., 1959. 51 pp. Calculation of the zero-lift wave drag of slender wings with certain fixed properties by the use of slender-body theory. The cross-sectional area distributions of the wings are taken to be polynomials and the fixed properties of the wings correspond to fixed first and second derivatives of the area distributions at the apex and rear end. The drag for delta wings of rhombic cross sections is calculated by thin-wing theory without the slenderness assumption. Comparisons between the drag coefficients calculated by both theories are made for a series of wings to investigate the applicability of slender theory. The calculations by both theories suggest that it should be possible to design thickness distributions which have drags as low as that of the so-called Lord V area distribution on plan forms for which the Lord V distribution is unsuitable. Further, this can be achieved when the thickness near the apex and the slope at the trailing edge are restricted.

ON THE APPLICATION OF WING PROJECTED AREA DISTRIBUTIONS TO THE DESIGN OF

WING-FUSELAGE COMBINATIONS AT SUPERSONIC SPEEDS. B. M. Ryan. Douglas Rep. SM-23765, Dec., 1959. 32 pp. Calculation of the average area distribution of a delta wing with a simple thickness distribution. The wing is combined with fuselages in various wing volume to fuselage volume ratios such that the combination of the average wing plus fuselage area distributions has a Sears-Haack shape. The results are general over the supersonic Mach number range and may be scaled by an adjustment of the streamwise dimensions. Wing-fuselage combinations are drawn for a Mach number of 1.414 and a wing thickness of 8.5% and then scaled to a Mach number of three which results in a wing thickness of 3%.

LONGITUDINAL AERODYNAMIC CHARACTERISTICS OF A HIGH-SUBSONIC-SPEED TRANSPORT AIRPLANE MODEL WITH A CAMBERED 40° SWEPTBACK WING OF ASPECT RATIO 8 AT MACH NUMBERS TO 0.96. Appendix - DERIVATION OF FORMULAS FOR WINGS WITH UNIFORM CHORDWISE LOADING IN SONIC FLOW. A. R. Heath, Jr. US, NASA TN D-218, Feb., 1960. 88 pp. Investigation to determine the performance of a wing of relatively high aspect ratio and sweepback as part of a complete transport configuration which included pylon-mounted nacelles. The wing was cambered by using linear theory for the special case of sonic velocity. The effects of fuselage shape on drag were explored, particularly the effects of a fuselage contoured to fit in the flow field of the cambered wing. In addition, methods of increasing the Mach number at which the abrupt rise in drag occurs were also investigated. For this purpose, inboard extensions on the wing leading edge and special bodies near the trailing edge were added.

AEROELASTICITY

CALCULATED RESPONSES OF A LARGE SWEPTWING AIRPLANE TO CONTINUOUS TURBULENCE WITH FLIGHT-TEST COMPARISONS. Appendix A - METHOD OF FREQUENCY-RESPONSE CALCULATION. Appendix B - LIFTING-SURFACE TECHNIQUE FOR DETERMINING AERODYNAMIC FORCES AND MOMENTS. F. V. Bennett and K. G. Pratt. US, NASA TR R-69, 1960. 61 pp. 13 refs. Discussion showing that the calculated responses of symmetrical airplane motions, wing deformations, and wing loads due to gusts compare favorably with available flight-test results. These calculated responses are based on random-process theory, five degrees of freedom, lifting-surface aerodynamics, and one-dimensional vertical turbulence. The extent to which various degrees of freedom contribute to the responses is examined and, in this connection, the relative effects of static and dynamic aeroelasticity are determined.

VIBRATIONS OF A THICK-WALLED CYLINDRICAL SHELL - COMPARISON OF THE EXACT THEORY WITH APPROXIMATE THEORIES. J. E. Greenspon. ASA J., May, 1960, pp. 571-578. 23 refs. Navy-supported comparison of the results for vibrations of an elastic cylinder, as predicted by a number of approximate shell theories, with the results of the exact theory. It is found that the membrane theory of shells is accurate for predicting frequencies and displacement ratios of cylinders with appreciable thickness. Furthermore, the theories which include bending effects as well as membrane effects are good at even the shorter wavelengths; and the theories which include rotatory inertia and shear are accurate over most of the wavelength spectrum of the lowest branch of rather thick shells. However, for the very thick shell (with a ratio of inside radius to outside radius less than 0.5), only the exact theory shows the full characteristics of the displacement distribution.

CHEMISTRY

THE INTERACTIONS BETWEEN NITROGEN AND OXYGEN MOLECULES. W. E. Meador, Jr. US, NASA TR R-68, 1960. 52 pp. 30 refs. Analysis and investigation of Lippincott's delta-function model for atomic interactions. By differentiation between the K- and L-shell electrons and by the introduction of a variable parameter in the expression of the delta-function strength, this model is extended to cover homonuclear molecules more complex than hydrogen. In addition, modifications are made which allow treatments of diatomic, heteronuclear molecules. This theory, in conjunction with a reasonably extensive study of resonance, dispersion, and configuration interaction phenomena, as well as the use of simple quantum mechanical arguments, is then applied to the N_2-N_2, N_2-O_2, and O_2-O_2 interactions.

FUELS & LUBRICANTS

PROPERTY REQUIREMENTS FOR LIQUID ROCKET PROPELLANTS. Appendix - DERIVATION OF SPECIFIC IMPULSE. E. M. Goodger. Coll. of Aeronautics, Cranfield, Note No. 97, Nov., 1959. 32 pp. 12 refs. Evaluation of rocket fuels by comparison of performance and handling characteristics and assessment of their overall suitability by examining the propellants individually. It is concluded that a high heat of reaction is a basic requirement for a rocket propellant pair, but this is modified by the thermodynamic behavior of the combustion gas in the propelling nozzle. A high combustion temperature is necessary for high thrust, but cooling problems are intensified and certain propellants only are suitable as coolants. A general increase in specific impulse is found with a decrease in specific gravity of the propellant mixture, while an increase in volume impulse is found with an increase in specific gravity of the mixture. Liquid hydrogen offers the ultimate in specific impulse for propellants and liquid fluorine for oxidants, but both pose severe handling difficulties. Hydrocarbon fuels still represent the best practical compromise for rocket applications with noncarbon hydrides the next most attractive. The slurry fuels are found most suited to air breathing propulsive units.

MACHINE ELEMENTS

Rotating Discs & Shafts

A FURTHER CREEP ANALYSIS FOR ROTATING SOLID DISKS OF VARIABLE THICKNESS. B. M. Ma. Franklin Inst. J., May, 1960, pp. 408-419. Calculation of stress distributions for rotating solid discs, based on the Tresca condition and its associated flow rule. The stress analysis on a variable-thickness and uniform-temperature disc at steady-state conditions is performed using an exponential function stress-creep-rate relation. For the purposes of comparison, the stress distributions for the constant-thickness and uniform-temperature disc are also given. It is found that the stress distributions over certain central portions of the disc are quite different between the variable- and constant-thickness discs.

MATHEMATICS

Physical Applications

TOPOLOGICAL ASPECTS OF STRUCTURAL LINEAR ANALYSIS. J. C. de C. Henderson. Aircraft Eng., May, 1960, pp. 137-141. Analysis showing how the knowledge of the topology of the structure can be exploited to improve the conditioning of the associated equations of compatability. Owing to difficulties inherent in the design of any automatic procedure for the reduction to canonical form, a method of condensation is evolved for complex multimember structures. In this way, the large-scale features of the structure are taken into account without neglecting the effect of local characteristics.

MISSILE, ROCKET, & SPACE TECHNOLOGY

SATELLITE PRESSURE LOSSES CAUSED BY METEOROID IMPACTS. M. Kornhauser. ARS J., May, 1960, pp. 475-479. Analysis considering the prediction of the frequency of hull penetration of a satellite capsule by meteoroids. Estimates are made of the frequency of encounters with meteoroids and the cratering effect of each impact. The cratering effects are based on the correlation of recent laboratory experimentation using hyper-velocity particles; and very conservative estimates of impact frequency are employed. The resulting calculations of percentage of hull area covered by holes, and loss of internal pressure versus time, are expected to be conservative for design purposes. Application of this method to a manned satellite capsule having a given surface area and time of exposure to meteoroids results in predictions of the following: probability of penetration of several hull designs, time required for air pressure to drop to 1/3 atm, and weight of reserve air needed to replace leakage and maintain internal pressure at 1 atm.

Ballistics, Re-Entry

THE THEORY OF CORRECTIONAL MANOEUVRES IN INTERPLANETARY SPACE. D. F. Lawden and R. S. Long. Astronautica Acta, Fasc. 1, 1960, pp. 48-60. USAF-supported analysis considering the elements of the interplanetary trajectory consisting of three arcs: (a) in the vicinity of the planet of departure, (b) in interplanetary space, and (c) in the vicinity of the planet of arrival. Since the main correcting actions will occur in arc (b), the details of this orbit are established. It is found that the correctional maneuvers are independent of all small perturbing forces, so that the rocket track can be considered to be a Keplerian arc that is followed under the attraction of the sun alone. The calculations are reduced to a substitution of the observed divergence from a precomputed track into given formulas, the coefficients of which can all be determined prior to departure and stored in a computer.

Guidance, Control, Stability

FIXED-BASE SIMULATION STUDY OF A PILOT'S ABILITY TO CONTROL A WINGED-SATELLITE VEHICLE DURING HIGH-DRAG VARIABLE-LIFT ENTRIES. Appendix A - EQUATIONS OF MOTION OF A SATELLITE VEHICLE DURING REENTRY FOR α_{trim} NEAR 90°. Appendix B - SOME PROBLEMS INHERENT TO THE ANALOG SIMULATION OF TRAJECTORIES. J. M. Eggleston, Sheldon Baron, and D. C. Cheatham. US, NASA TN D-228, Apr., 1960. 60 pp. Presentation of test results for a vehicle simulated in five degrees of freedom by using a fixed-base simulator. The tests showed that a pilot can successfully control the trajectory of the vehicle in several ways. A desired value of deceleration or rate of descent may be established and maintained. For entry angles up to -3°, the deceleration could be held between 3g and 4g. At entry angles of -6°, the pilot was able to limit the maximum deceleration between 7g and 8g. Inadvertent coupling of the pitch- and roll-control motions by the pilot was noted when using a grip-type side-arm controller. Replacing this controller with a finger-tip side-arm controller eliminated the inadvertent coupling and made it possible for the pilot to fly simulated entries with zero damping of the vehicle's angular motions. Lack of static stability in yaw for this vehicle was found to be objectionable. Adverse aerodynamic-control moment coupling was simulated. Such control coupling was considered undesirable but pilots could adapt themselves to control the vehicle even with large amounts of coupling, provided the vehicle was well damped.

SISTEMA DLIA OPREDELENIIA PARAMETROV DVIZHENIIA TELA V PROSTRANSTVE. G. O. Fridlender. AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom., Nov.-Dec., 1959, pp. 108-117. In Russian. Investigation of a system for determining the parameters of a body moving in space. It is shown that the application of geosystems (systems for vehicles moving at a relatively low speed along the surface of the earth) in interplanetary space involves difficulties due to the weightlessness of sensitive accelerometer elements and, therefore, the absence of correction which leads to periods of nonturbulence. The difficulty is overcome by the method of double integration of the discrepancy between the data furnished by the system, which are converted to correspond to the

optical system oriented toward the sun or the planet, and the real position of the optical system. Damping can be introduced into the system without leading to accelerations which affect geosystems.

EXPLORATORY STATISTICAL ANALYSIS OF PLANET APPROACH-PHASE GUIDANCE SCHEMES USING RANGE, RANGE-RATE, AND ANGULAR-RATE MEASUREMENTS. Appendix A - SAMPLE CALCULATIONS. Appendix B - ERROR ANALYSIS OF RANGE - RANGE-RATE SCHEME OF MEASUREMENT. Appendix C - APPLICABILITY TO OPTICAL OR INFRARED AND GYROSCOPIC SYSTEMS OF INSTRUMENTATION. Appendix D - STATISTICAL METHODS. D. P. Harry, III, and A. L. Friedlander. US, NASA TN D-268, Mar., 1960. 81 pp. 20 refs. Evaluation of control logic on the basis of guidance accuracy and velocity-increment requirements for trajectory correction. A system of measurement based on radar or radio techniques in conjunction with gyroscopic determination of an inertial reference direction is accurately approximated. Results indicate that guidance logic is relatively insensitive to mission energy or to residual errors from midcourse guidance that have a predictable effect on velocity-increment requirements. The guidance scheme is, however, sensitive to the altitude of the target perigee. Low-altitude targets are more accurately attained than those at higher altitude. A large range of angular-rate measurement errors is considered ($\dot{\Theta}$ being defined as the rate of change of the radius vector to the target body with respect to an inertial reference direction), and use of the radar-gyroscopic system is considered feasible for guidance to atmospheric-drag deceleration accuracies with instruments of current performance expectations. A strong trend toward heavily "restrained" and "damped" guidance systems is indicated, and a large number of corrections in trajectory following initiation of guidance at long range would be desired.

Spacecraft

SATELLITE PERTURBATIONS FROM EXTRATERRESTRIAL GRAVITATION AND RADIATION PRESSURE. F. T. Geyling. Franklin Inst. J., May, 1960, pp. 375-407. Presentation of the equations of motion for a satellite, written in terms of displacement components relative to the unperturbed, elliptic orbit. A moving system of coordinates is used which consists of an orthogonal triad whose origin is always located at the nominal satellite position on the elliptic orbit. This approach differs from the conventional one by way of Lagrange's planetary equations in that the primary results are expressions for the satellite position rather than the osculating orbit elements. Calculations are carried out for the effects of perturbations in the initial conditions of satellite motion and perturbations due to oblateness, lunar and solar gravitation, and solar radiation pressure. Numerical examples illustrate the performance of a thin mylar balloon acting as a passive communication satellite.

POWER PLANTS

AUFGABEN UND MÖGLICHKEITEN BEI DER ENTWICKLUNG VON RAKETEN-TREIBSTOFFEN UND -ANTRIEBSSYSTEMEN. A. Dadieu. Raketentech. & Raumfahrtforsch., Apr.-June, 1960, pp. 41-45. In German. Survey of the characteristics, present status, and performance limitations of chemical rocket propulsion. The study covers theoretical bases and practical problems involved in the use of liquid hydrogen as rocket fuel, future development of nuclear rocket propulsion systems, such as the convective thermal system (Rover-type), and the possibility of heating a working fluid through atomic explosions. Problems associated with future projects are also discussed.

ÜBER KNALLWELLENDRÜCKE IN HEISSWASSER-FISSIONSRAKETEN. E. Sänger. Raketentech. & Raumfahrtforsch., Apr.-June, 1960, pp. 46-49. In German. Comparative evaluation of the expected exhaust velocities of chemical, convective fission, and hot-water fission rockets. In the thermal nuclear rocket system, the working fluid is to be heated to very high temperatures by means of successive explosions of small atom bombs. In this case, combustion chamber dimensions are determined through the stresses in chamber walls, due to the shock wave in the water plasma resulting from the explosion process. The importance of studies of these prospective shock wave pressures within the atomic-bomb heated, hot-water propelled, fission rocket is stressed.

ATOMRAKETEN FÜR RAUMFAHRT. E. Sänger. (Phys. Gesellschaft Meeting, Zurich, Jan. 21, 1960.) Astronautica Acta, Fasc. 1, 1960, pp. 3-15. 10 refs. In German. Evaluation of the types of nuclear reaction, such as fission, fusion, and conversion of matter into energy. In addition to the industrially developed types of fission rockets - i.e., convective and electric, such versions as hot-water and photon rockets are discussed. Examples for terrestrial, slow interplanetary, fast interplanetary, and interstellar travel are evaluated, emphasizing the duration of such trips. The expected performance of future propulsion systems for space vehicles is discussed in terms of velocity and range.

ONE-DIMENSIONAL ANALYSIS OF ION ROCKETS. H. R. Kaufman. US, NASA TN D-261, Mar., 1960. 35 pp. 12 refs. Study of space-charge effects in ion and electron accelerators and the problems associated with mixing beams from such accelerators. Heavy ions are found to be particularly desirable for high current density when ion-accelerator lengths are limited by manufacturing tolerances rather than dielectric strength. The similar geometrical design of electron and ion accelerators leads to excessive electron velocities or exit areas, or both, probably even when the accelerate-decelerate principle is utilized for the electron accelerator. Excessive electron velocities cause only part of the electron current

to go downstream when neutralization is attempted. The high-electron-velocity mixed-beam solutions are accompanied by upstream electron currents; therefore, the ion accelerator must be able to withstand electrons bombarding the exit. The accelerate-decelerate principle is also useful for preventing harm to the ion accelerator from electron bombardment, because the electrons will be unable to pass through the field between the accelerating and decelerating electrodes to reach the ion source.

Jet & Turbine

TURBOJET THRUST AUGMENTATION: FLIGHT MEASUREMENTS OF THE TURBINE BLADE COOLING ACCOMPANYING THE PRE-TURBINE INJECTION OF REHEAT FUEL WITH AN ORENDA 14 ENGINE IN A SABRE 6 AIRCRAFT. E. P. Cockshutt, G. G. Levy, and C. R. Sharp. Canada, NRC Aero. Rep. LR-271, Jan., 1960. 41 pp. Presentation of turbine blade temperature data, obtained with a thermocouple-slipring instrumentation system. The data are presented for an Orenda 14 engine, which was flight tested both with and without reheat at altitudes ranging from 20,000 to 50,000 ft. The blade temperatures in the unreheated engine were found to be determined primarily by the variation in the turbine outlet (gas) temperature with flight conditions. The first-stage turbine blades were cooled by the pre-turbine injection of the reheat fuel by a maximum of 150°C. under sea-level-static conditions; as had been predicted from simple heat transfer theory, the maximum cooling declined to about half this value at 50,000 ft. No significant cooling of the second-stage turbine blades was detected at any flight condition.

Rocket

APPLICATION OF VARIOUS TECHNIQUES FOR DETERMINING LOCAL HEAT-TRANSFER COEFFICIENTS IN A ROCKET ENGINE FROM TRANSIENT EXPERIMENTAL DATA. C. H. Liebert, J. E. Hatch, and R. W. Grant. US, NASA TN D-277, Apr., 1960. 33 pp. 10 refs. Presentation of time-temperature data obtained from copper plugs installed in a solid-wall ammonia-oxygen rocket. Local values of heat-transfer coefficient were calculated from six selected analytical methods varying in complexity from approximate methods to rather complex solutions of the partial differential equations of unsteady heat conduction. The resulting heat-transfer coefficients, as well as an evaluation of each of the six methods, are presented. The integration method appears to be the best of the six methods from the standpoint of estimated accuracy, ease of calculation, and applicability.

ACOUSTIC RESONANCE IN SOLID PROPELLANT ROCKETS. F. T. McClure, R. W. Hart, and J. F. Bird. J. Appl. Phys., May, 1960, pp. 884-896. 14 refs. Navy-supported study in which the solid propellant is considered as one of the acoustic media in a rocket motor. The viscoelastic properties of the solid, along with those of the burned gases, determine the characteristic modes of the system corresponding to the particular boundary conditions imposed on these media by the metal components. In addition, these properties of the media contribute strongly to the selection of the regions of stability and instability of the system and, therefore, to the intermittent and sporadic nature, characteristic of resonant burning in solid propellant motors. Calculations are carried out to illustrate the general nature of the phenomenon, and the relationship of these studies to a variety of experimental observations is discussed.

PROPELLANT VAPORIZATION AS A CRITERION FOR ROCKET-ENGINE DESIGN: EXPERIMENTAL EFFECT OF COMBUSTOR LENGTH, THROAT DIAMETER, INJECTION VELOCITY, AND PRESSURE ON ROCKET COMBUSTOR EFFICIENCY. B. J. Clark. US, NASA TN D-258, Apr., 1960. 27 pp. Investigation of the combustion efficiency of a heptane-oxygen rocket combustor at various combustor lengths, contraction ratios, combustor pressures, and injection velocities of the heptane. It is shown that efficiency increases generally with injection velocity, pressure, combustor length, and contraction ratio, except at some of the lower contraction ratios and injection velocities. From the experimental data and analytical vaporization-rate calculations, apparent drop sizes are calculated. These sizes correlate the data well, show similar trends, and are in the same range as drop sizes measured under cold-flow conditions.

ROTATING WING AIRCRAFT, HELICOPTERS

COMPRESSIBILITY EFFECTS ON THE HOVERING PERFORMANCE OF A TWO-BLADE 10-FOOT-DIAMETER HELICOPTER ROTOR OPERATING AT TIP MACH NUMBERS UP TO 0.98. J. W. Jewel, Jr. US, NASA TN D-245, Apr., 1960. 28 pp. 10 refs. Presentation of results of hovering tests showing that, as the rotor tip speed is increased, compressibility losses occur at progressively lower rotor mean lift coefficients. At tip Mach numbers of 0.90 and above, compressibility losses were present even at zero thrust. Induced velocity distribution beneath the plane of the rotor appeared to be relatively unaffected by tip Mach number. The major factor influencing the noise level of the rotor was tip speed. Smaller increases in noise were incurred by increases in thrust.

THE LATERAL STABILITY AND CONTROL OF THE TANDEM-ROTOR HELICOPTER. A. R. S. Bramwell. Gt. Brit., RAE Rep. Naval 4, Jan., 1960. 39 pp. 10 refs. Investigation showing that a tall fin may provide an effective dihedral several times larger than that of the rotors and lead to an unstable Dutch roll oscillation which becomes progressively worse with an increase of speed. The corresponding spiral mode is stable. If the rotors provide the only contribution, the Dutch roll oscillation is stable but the spiral mode may become unstable. Simple approximations are given

for the estimation of the damping and period of the stability modes and show quite close approximation to the more exact calculations.

STRUCTURES

Cylinders & Shells

COMPARISON OF YIELD CONDITIONS FOR CIRCULAR CYLINDRICAL SHELLS. Antoni Sawczuk and P. G. Hodge, Jr. Franklin Inst. J., May, 1960, pp. 362-374. Navy-sponsored analysis considering the yield condition for a rigid-plastic circular cylindrical shell subjected to axially symmetric loading, in terms of the circumferential hoop stress n and the axial bending moment m. Different yield conditions are obtained depending on whether the shell is of homogeneous or ideal sandwich construction, and on whether the shell material satisfies Tresca's or Mises' yield condition. The example of a long shell subjected to a ring of pressure at its midpoint is considered for each of the four shell yield conditions, as well as for a simple "limited interaction" approximation. Complete stress and velocity fields are determined, the limit load is found, and the extent of the plastic region is determined. The results are assessed in terms of the theorems of limit analysis.

ANALYSIS OF ELASTIC-PLASTIC STRESS DISTRIBUTION IN THIN-WALL CYLINDERS AND SPHERES SUBJECTED TO INTERNAL PRESSURE AND NUCLEAR RADIATION HEATING. Appendix A - DETERMINATION OF STRESS AND STRAIN DISTRIBUTION IN CYLINDER. Appendix B - CALCULATION OF PLASTIC STRAINS. Appendix C - ANALYSIS OF SPHERE. Appendix D - CALCULATION OF TEMPERATURE DISTRIBUTION FOR SPHERE. D. F. Johnson. US, NASA TN D-271, Apr., 1960. 34 pp. Application of a finite-difference method combined with a technique of successive approximations to calculate the stresses in shells subjected to internal pressure, symmetrical nuclear heating, and inside-wall cooling. For given values of pressure load (pressure times radius) and heat flux, there is a minimum possible strain for each vessel configuration. Furthermore, for a given value of pressure load, the minimum strain for different heat fluxes occurs at essentially the same wall thickness. The optimum thicknesses and corresponding strains for the sphere were approximately half those of the cylinder for the same loads.

PRESSURE CABIN ANALYSIS: AN EXTENSION TO EXISTING THEORY. D. S. Houghton and A. S. L. Chan. Aircraft Eng., May, 1960, pp. 126-131. Analysis to obtain a more accurate estimate of the stresses in a stiffened pressurized cylinder by including in the differential equation a term arising from the curvature of the deformed cylinder. This effect is neglected in the standard work of Timoshenko, but when the deformation is appreciable, the effect of this term becomes considerable. A skin flexibility parameter ζ appears as a nondimensional coefficient in the new equations and is inversely proportional to Et^2 (E being Young's modulus of the skin and t the skin thickness.) The larger this parameter, the more the stress distribution deviates from that predicted by the standard theory. Two cases are examined: when $\zeta < 1$, as is usual with a stringer reinforced cabin and when $\zeta \geq 1$, the usual case for pure shells having no stringer reinforcements. Comparison is made graphically with standard theory. It is noted that the refinement to the equations results in the bending moment being generally reduced and the hoop force being increased.

THE THEORY OF MOMENTLESS SHELLS OF REVOLUTION. V. Z. Vlasov. (AN SSSR Otd. Tekh. Nauk Izv., May, 1955, pp. 55-84.) US, NASA TT F-6, Apr., 1960. 36 pp. Translation. Presentation of general homogeneous solutions for the equations of the membrane theory of shells of revolution of both positive and negative Gaussian curvature. Solutions are obtained of a number of boundary-value problems of edge-loaded shells and compound shells loaded at their junctures, including a compound shell made of conical segments with stiffeners at the junctures.

THE EFFECT OF AXIAL CONSTRAINT ON THE INSTABILITY OF THIN CIRCULAR CYLINDRICAL SHELLS UNDER EXTERNAL PRESSURE. Josef Singer. Israel Inst. Tech. Dept. Aero. Eng. TN 1 (AFOSR TN 60-165), Sept., 1959. 20 pp. Application of the Rayleigh-Ritz method to calculate the effect of axial elastic restraint in the case of hydrostatic pressure for a wide range of parameters, which are presented as design curves for the percentage increase in critical pressure. The analysis is carried out for reloading and for those which come into action only at the onset of buckling. The difference between these two types of restraint is shown to be very small.

Fatigue

FATIGUE RESISTANCE. C. R. Smith. Aircraft Eng., May, 1960, pp. 142-144. Study concluding that contrary to the general conception of adding weight for fatigue resistance, it is sometimes possible to reduce the fatigue hazard by removing the weight. The theory of having bearing area, tear-out area, and tension area sufficient to develop the full shear strength of a rivet is not necessarily sound when fatigue life is considered. Marked improvements in fatigue resistance can be achieved by reducing the underlying areas to such an extent that they are incapable of inducing loads causing fatigue failures of the main structure. Results of tests involving fatigue failure are given, and seven basic considerations in the design of fatigue resistant structures are listed.

Plates, Stiffened

OBLICZANIE PŁASKICH TARCZ SEGMENTOWYCH Z ODKSZTAŁCALNYMI ELEMENTAMI POPRZECZNYMI. Henryk Frączkiewicz. Arch. Budowy Maszyn, No. 1, 1960, pp. 53-74. In Polish, with summaries in English and Russian.

Analysis considering concentrated forces acting on a flat panel with deformable ribs. The variations of the internal forces are given in the form of vector functions, and the effect of rib rigidity upon the distribution of internal forces is considered. As an example, solutions are given for an infinitely long three-strip panel.

Plates with Holes

THE BENDING AND TWISTING OF A FLAT ELASTIC PLATE WITH A REINFORCED CIRCULAR HOLE. R. Hicks. Aero. Quart., May, 1960, pp. 137-158. 12 refs. Presentation of solutions for stress distributions in plates having small deflections. The reinforcement is chosen so that the ratio of its radial width to the diameter of the hole is small; this implies that there is no stress variation across radial sections of the reinforcement. Using the classical theory of bending, expressions are obtained for the boundary conditions at the junction of the reinforcement and plate, and for the moments and shear forces induced in these elements. The following particular problems are considered: (a) uniform bending about one or two axes, and (b) uniform twisting about two axes. For the particular case of uniform bending about one axis, data are obtained for the stress concentration around holes for plates and reinforcements having a reasonably wide range of practical dimensions.

Thermal Stress

DEFORMATION AND THERMAL STRESS OF RECTANGULAR BEAMS OR FLAT STRIPS HEATED AT ONE SURFACE. Masuji Uemura. U. Tokyo Aero. Res. Inst. Rep. 352, Mar., 1960. 49 pp. Analysis considering the effect of deformation during the transient heating condition. The two cases of clamped and simply supported ends, where axial displacements are restrained, are discussed taking into account the finite deformation. When the temperature distribution along the length exists such that $d^2T_2/dx^2 \neq 0$ (T_2 being the temperature gradient through the thickness and x the axial coordinate), the beam deflects from the beginning of heating. When $d^2T_2/dx^2 = 0$, the clamped beam does not deflect initially even if T_2 exists along the beam, but the simply supported beam deflects initially if T_2 exists at both ends. In the other cases, it is seen that the deformation behavior corresponds to Euler buckling.

THERMODYNAMICS

Combustion

A STUDY OF SUPERSONIC COMBUSTION. R. A. Gross and Wallace Chinitz. J. Aero/Space Sci., July, 1960, pp. 517-524, 534. 24 refs. USAF-supported investigation of steady, stable, plain, and oblique detonation waves in a steady flow supersonic tunnel. Ignition conditions and properties across the wave were measured. The local-wave fluid-dynamic properties agree well with detonation theory. An ignition hysteresis phenomenon which has important theoretical consequences was discovered. Experimental behavior of these detonations and their possible utility are discussed.

COMBUSTION OF PROPELLANT DROPLETS. R. Sandri. Canada, NRC DME/NAE Quart. Bul. No. 4, Oct. 1-Dec. 31, 1959, pp. 37-44. Study of the combustion of droplets of fuel which are injected in a continuous spray into a hot combustion chamber such as a jet chamber. The phenomenon of spray combustion is investigated using a single droplet burning in an infinite atmosphere as a basis for the discussion. After injection, the droplet will rapidly lose its initial velocity and become practically motionless relative to the surrounding air. Evaporation takes place before burning. Part of the heat developed by the combustion is conducted to the droplet surface where it evaporates the liquid. The vapor then streams outward in a radial direction until it enters the combustion zone. The remainder of the combustion heat flows outward from the flame zone to the atmosphere. The total heat transport by conduction and mass flow inside the flame front, where there is no heat development due to chemical reaction, is examined and the rate of evaporation is determined. The decrease of the droplet diameter in time is investigated and Godsave's, Hall and Diedrichsen's, and Saad's experiments studying this process are described. It is found that difference in the squares of the initial and present droplet diameters is proportional to time, and inversely proportional to the density of the fuel. The physical processes of diffusion and gas flow as rate-determining factors are evaluated. The influence of chemical reactions is found to be negligible. Each of the discussed phenomena is mathematically formulated, and the role of the "effective flame radius" in the discrepancies between theoretical and experimental results is pointed out. The basically different mechanism underlying the vaporization and combustion of monopropellants is also briefly discussed.

PROPAGATION OF FLAMES SUPPORTED BY A ZEROETH-ORDER CHEMICAL REACTION. J. O. Hirschfelder and S. S. Van Domelen. Phys. Fluids, Mar.-Apr., 1960, pp. 210-216. Navy-supported analysis considering the properties of zeroth-order chemical reactions that are suited to serve as "global" reactions for complicated flame systems involving either three-dimensional geometry or time-dependent phenomena. These characteristics are independence of diffusion and the completion of chemical reactions at a finite point in space. Extensive tables are given for the properties of steady-state one-dimensional zeroth-order flames. Good agreement with the numerical calculations is obtained by using a simple approximation (based upon the Adams and Wilde approach) which results in simple closed-form expressions for flame variables.

STABLE COMBUSTION OF A HIGH-VELOCITY GAS IN A HEATED BOUNDARY LAYER. D. L. Turcotte. J. Aero/Space Sci., July, 1960, pp. 509-516. Study of stable combustion processes

that may be achieved by either of two conceptual mechanisms. In one mechanism it is pictured that the heat transfer to the wall quenches the propagating flame at a certain distance from the surface. In the second mechanism it is conceived that the hot surface provides a continuous source of ignition in much the same manner that the hot recirculation zone of a bluff body flame holder provides continuous ignition to the gas flowing around it. An investigation is described which shows under what conditions the continuous ignition mechanism provides the appropriate model, and also how the two models are related. With a turbulent boundary layer and a wall temperature above 1,700°F., the characteristic time was found to be a systematic and reproducible variable. These observations led to the conclusion that a continuous ignition mechanism governs stabilization in heated turbulent boundary layers. A rational explanation is made for the transition from the low-speed mechanism, known to be applicable in unheated turbulent boundary layers and heated laminar boundary layers, to the ignition mechanism applicable in heated turbulent boundary layers.

OB ANALOGII MEZHDU GORENIEM V DETONATSIONNOI VOLNE I V RAKETNOM DVIGATELE. Iu. N. Denisov, Ia. K. Troshin, and K. I. Shchelkin. AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom., Nov.-Dec., 1959, pp. 79-89. 17 refs. In Russian. Establishment of an analogy between the combustion process in a detonation wave and that in a rocket engine. The instability criterion is derived for various propellant mixtures; the nature and mechanism of inhomogeneities in the front of the detonation wave is studied, showing the presence of two types of detonation waves - pulse and spin. For pulse and spin detonation, the role of the oblique shock waves in the mechanism of high-frequency oscillations is determined experimentally, and the absence of the two-dimensional wave front is established.

Heat Transfer

NUMERICAL COMPUTATION OF AERODYNAMIC HEATING OF LIQUID PROPELLANTS. J. L. Kramer, H. H. Lowell, and W. H. Roudebush. US, NASA TN D-273, Apr., 1960. 28 pp. Application of the one-dimensional aerodynamic heating theory to the calculation of heat input to rocket propellant tanks. The heat-transfer coefficient between the liquid propellant and the wall is included and is found to have a large influence in some cases. Results of several examples are presented. The heat capacities of the insulation and the metal tank wall are not included. Examples are given which indicate the magnitude of the resulting error in several cases.

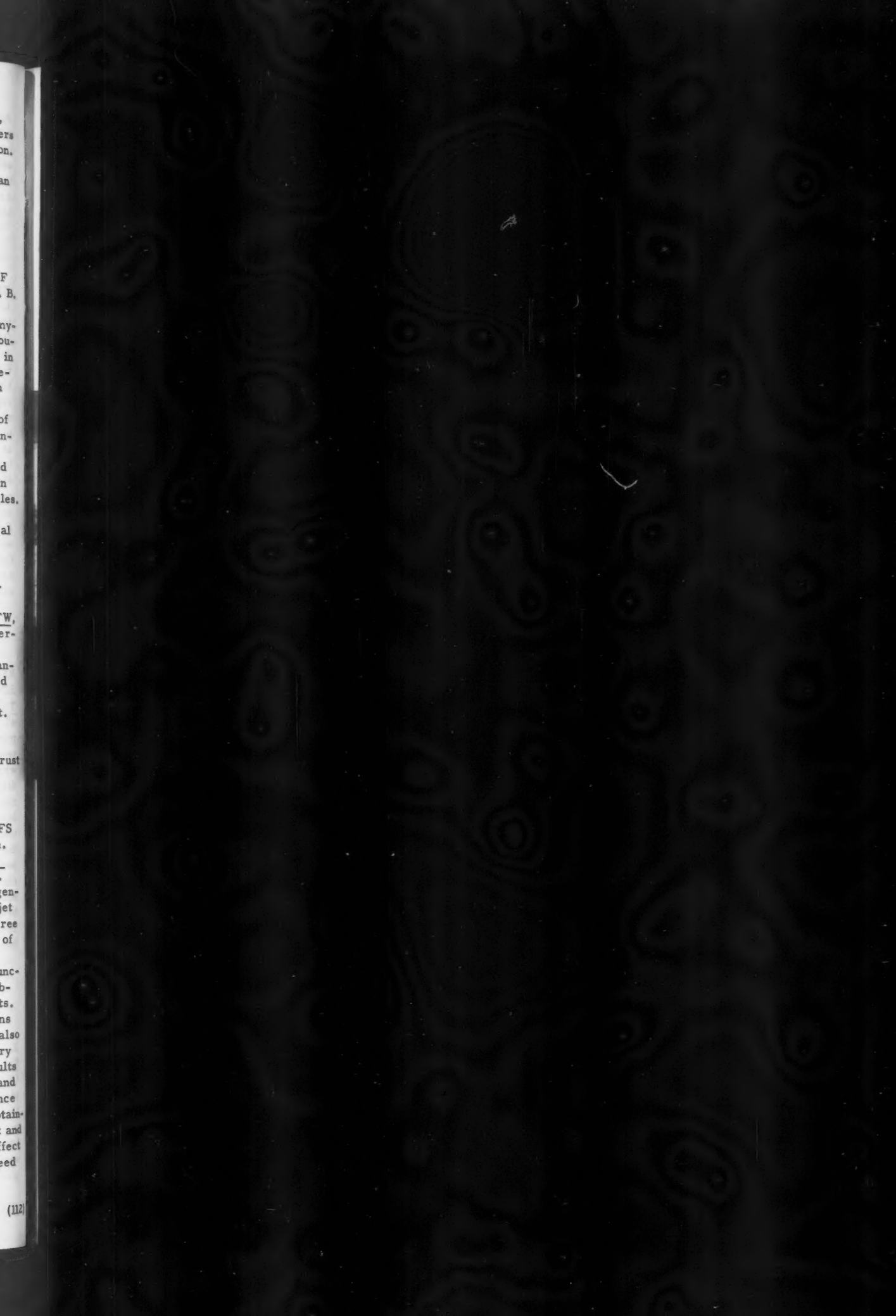
SOLAR HEATING OF A ROTATING CYLINDRICAL SPACE VEHICLE. A. Charnes and S. Raynor. ARS J., May, 1960, pp. 479-484. Study of solar heating in a space vehicle idealized as a thin walled circular cylinder rotating with uniform velocity about its geometric axis in which heat transfer by convection and heat exchange within the cylinder are negligible. The nonlinear problem is approximated through a perturbation analysis, and detailed estimates are made of the parameters of interest for various ranges of speed of rotation. An estimate of the error between the exact and perturbational approaches is made in the case of an illustrative example which might be expected to entail an extreme deviation.

VTOL & STOL

SOME QUALITATIVE CHARACTERISTICS OF A TWO-DIMENSIONAL PERIPHERAL JET. W. B. Nixon and T. E. Sweeney. Princeton U. Dept. Aero. Eng. Rep. 484, Sept., 1959. 16 pp. Army-sponsored investigation of base pressure distributions of a two-dimensional peripheral jet model in simulated hovering flight. Flow patterns are deduced from these distributions and verified with smoke studies. The standing vortex associated with this type of device is plotted as a function of altitude and angle of inclination, and the relationship between the vortex and static instability is shown for three initial jet angles. Also included is a brief discussion of the unsteady flow pattern generated at certain altitudes and initial jet angles. This flow is plotted and is shown to deteriorate into a Karman street, thus explaining the critical altitude reported by other investigators.

ZUR BERECHNUNG DER KURZSTARTLEISTUNGEN VON FLUGZEUGEN MIT SCHUB-SCHWENK-TRIEBWERKEN. H. M. Dathe. ZFW, Mar., 1960, pp. 61-67. In German. Study covering the horizontal take-off of aircraft equipped with tilt thrust units analyzed for different tilt angles. The assumption of constant take-off speed is introduced and used in the analysis of climb performance up to the obstacle clearance height. The take-off distances, calculated for a typical example, indicate the possibilities of using a VTOL aircraft for STOL operations over the thrust range of $S_0/G = 0.8$ and 1.0 (S being the thrust and G the weight).

SUR L'UTILISATION DES JETS PROPULSIFS A L'HYPERSUSTENTATION D'UN AVION. Ph. Poisson-Quinton and A. Bevert. Tech. & Sci. Aéronautiques, Sept.-Oct., 1959, pp. 295-316. In French. Survey of various methods of lift generation by means of jets and evaluation of the jet flap principle. Wind-tunnel experiments on three configurations of hypothetical aircraft capable of high speed with low aspect ratio wings are described. The lift and drag performance, as function of turbine thrust, is compared with that obtained by simple downward deflection of the jets. The longitudinal stabilization achieved by means of auxiliary jets in the nose of the fuselage is also studied. Included in the survey are preliminary studies of the ground effect principle with results of the effect of various parameters (intensity and orientation of the jets) as function of the distance from the ground. The similarity of results obtained on a platform and on jet flaps is pointed out and the possibility of using the favorable ground effect for take-off and landing application to high-speed aircraft is evaluated.



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mation to the downwash is obtained by a numerical integration, based on the $(n-1)^{th}$ approximation to the distribution of circulation, is used to deduce the loading over straight-tapered wings, as those used on sailplanes.

Asupra Rezistenţei de Undă şi Momentului de Ruliu Ale Aripilor cu Borduri de Atac Supersonice. M. Ionescu and Gh. Darie. *Stud. Cerc. Mec. Aplic.*, No. 3, 1959, pp. 683–693. In Rumanian. Calculation of the axial turbulent velocity, as well as drag and moment coefficients, for triangular wings with supersonic leading edges in homogeneous flow.

Further Comments on "Limiting Circulatory Lift of a Wing of Finite Aspect Ratio." H. S. Ribner. *J. Aero/Space Sci.*, June, 1960, pp. 460, 461.

L'Écoulement Supersonique Autour du Système Portant Aile-Fuselage Conique. Elie Carafoli and Dan Mateescu. (*Stud. Cerc. Mec. Aplic.*, No. 2, 1959, pp. 335–350.) *Rev. Méc. Appl.*, No. 3, 1959, pp. 377–390. In French. Study of the supersonic flow about a lifting system composed of a wing and a conical fuselage.

Aeroelasticity

Caractéristiques Aérodynamiques des Ailes Triangulaires Ayant un Mouvement Oscillatoire en Régime Supersonique. Ş. Săndulescu. (*Stud. Cerc. Mec. Aplic.*, No. 3, 1959, pp. 711–721.) *Rev. Méc. Appl.*, No. 4, 1959, pp. 581–590. In French. Study of the aerodynamic characteristics of triangular wings vibrating harmonically in supersonic flow.

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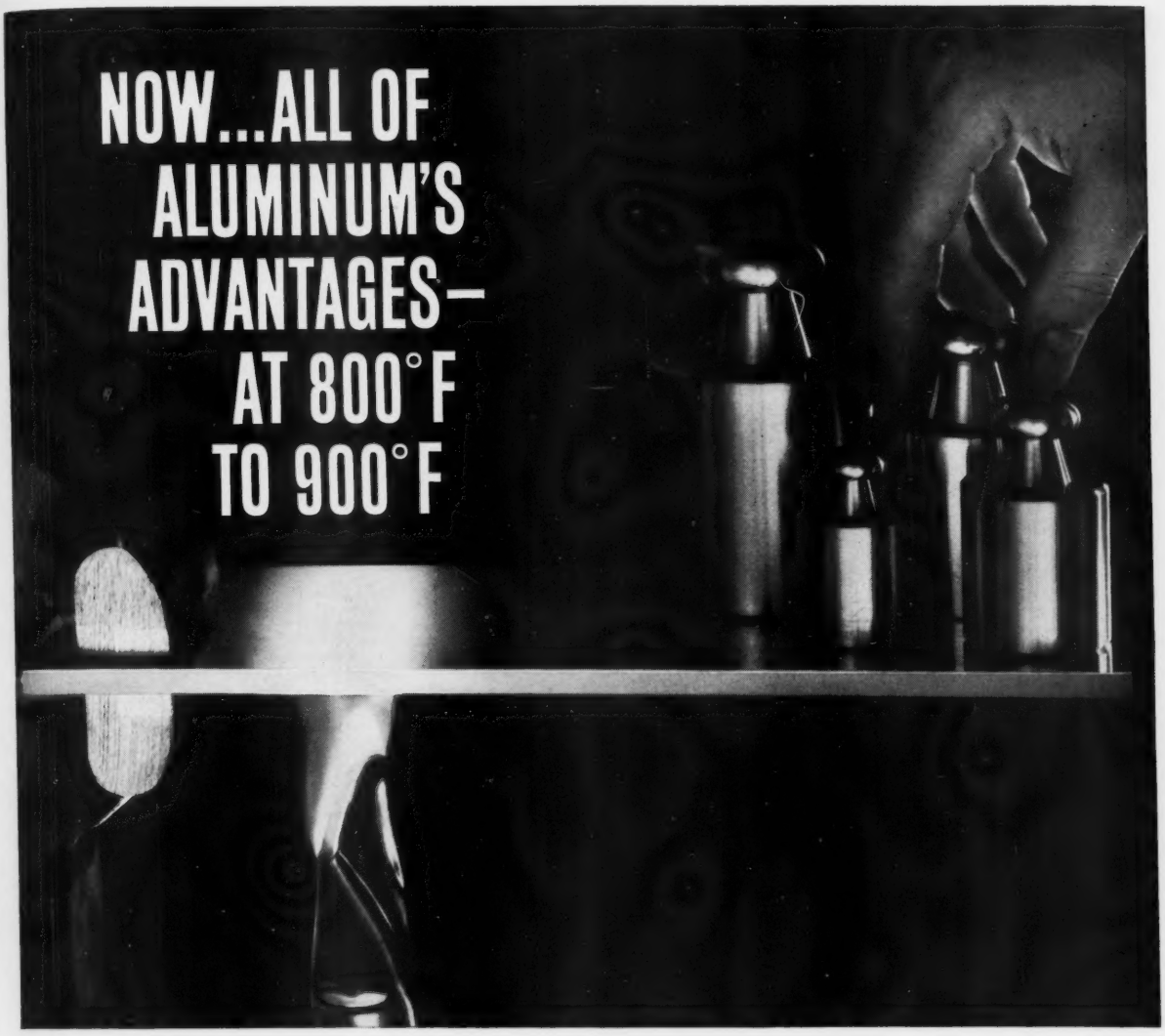

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ATTENTION IAS MEMBERS!

In accordance with plans reported in the June issue of Aero/Space Engineering, *the October, and first, issue of IAS News (prepared in newsletter format) will be published and mailed to the Institute's more than 16,000 graded members on Sept. 15 and on the 15th of each succeeding month.*

Plans to increase the technical article content of Aero/Space Engineering *will take effect with the October issue, which will continue to be published and mailed on the first of each month to IAS members plus several thousand other subscribers.*

This year's IAS Roster Issue of A/SE will appear next month.

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Problems of Interplanetary Navigation and Atmospheric Re-Entry. T. R. F. Nonweiler. *RAeS J.*, Mar., 1960, pp. 155–160. Discussion that includes the estimation of heat transfer, methods of surface cooling, comparison of long-range missiles between ballistic and winged types, consideration of recovery from a closed orbit and a choice of configuration for such a mission, and re-entry from parabolic orbits.

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properties of matter at temperatures of 2,000°C. to 50,000°C. It is found that the plasma jet makes possible the examination of vaporization phenomena under controlled conditions.

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Structures

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Practical Solution of Plastic Deformation Problems in Elastic-Plastic Range. Appendix A, B—**Calculation of Plastic Strains.** Appendix C—**Equations for Thin Circular Shell.** Appendix D—**Plastic Strain Charts.** Appendix E—**Long Solid Cylinder.** Appendix F—**Rotating Disk.** Appendix G—**Effect of Previous Plastic Strain.** A. Mendelson and S. S. Manson. *U.S., NASA TR R-28*, 1959. 24 pp. Supt. of Doc., Wash., $0.40. Presentation of a method of successive approximations which is illustrated by four examples, including a flat plate with temperature distribution across the width, a thin shell with axial temperature distribution, a solid cylinder with radial temperature distribution, and a rotating disc with radial temperature distribution.

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Testing Methods

A Study of Infra-Red Radiant Heating. R. Reymond. (*Etabliss. Aéro. Toulouse GP Rep. 1, Etude 20 P*, Apr., 1959.) *Gt. Brit., RAE Lib. Transl. 836*, Aug., 1959. 25 pp. Presentation of methods for determining the efficiency and response time of infrared heating installations of the type used to simulate kinetic heating of aircraft structures. Data are given on the efficiency of plane and cylindrical polished aluminum reflectors and on the response time of Philips C. 1076 infrared lamps.

K Ekonomickým Problémům Statických Zkoušek Letadlových Konstrukcí. Jan Drexler and Richard Mareš. *Zpravodaj VŽLÚ*, July-Aug., 1958, pp. 4–12. In Czechoslovak. Discussion of various factors affecting the economic efficiency of structural testing processes, such as the human factor, organization system, and complexity of the test specimen.

Thermal Stress

The Problem of Strain Accumulation Under Thermal Cycling. B. E. Gatewood. *J. Aero/Space Sci.*, June, 1960, pp. 461, 462. Presentation of a method to account for strain growth occurring in a beam structure subject to temperature-load cycling. The various aspects of the problem as to criteria for convergence and divergence of the strain accumulation are demonstrated by thermal-cycling of one element of a two-element structure.

The Problem of the Non-Steady State Surface Nucleus of Thermoelastic Strain in an Infinite Elastic Body with a Spherical Cavity. W. Piechocki. *Acad. Pol. Sci. Bul., Tech. Sci. Ser.*, No. 1, 1960, pp. 1–4.

A Note on Thermal Stresses in Hollow Cylinders. M. M. Stanišić and R. M. McKinley. *Ing.-Arch.*, No. 4, 1959, pp. 227–241. Extension of solutions obtained by Trostel for the stress field in hollow cylinders with axial and rotational symmetry subjected to a steady-state temperature field. A numerical method for obtaining higher accuracy is indicated.

Thermodynamics

Vapor-Liquid Equilibria of Ozone-Oxygen Systems. Ch. K. Hersh, R. I. Brabets, G. M. Platz, R. J. Swehla, and D. P. Kirsh. *ARS J.*, Mar., 1960, pp. 264–266. Investigation to verify the 1-atm vapor-liquid equilibrium curve and extend the data to a total pressure of 20 atm.

The Thermodynamic Properties of Fluid Helium. R. W. Hill and O. V. Lounasmaa. *Royal Soc. (London) Philos. Trans., Ser. A*, Mar. 31, 1960, pp. 357–395. 37 refs. Experimental investigation of helium in the temperature range from 3° to 20°K. and up to 100 atm pressure, ascertaining data from which all the thermodynamic properties may be calculated. The qualities measured are the specific heat at constant volume and the pressure coefficient at constant volume $(\partial p/\partial T)_v$, both as a function of temperature and density; and the pressure as a function of temperature at constant volume for a range of densities. The derivative $(\partial p/\partial T)_v$, from which the changes of entropy and internal energy with volume at constant temperature are calculated, is measured directly by a differential method.

Combustion

Nonlinear Pressure Oscillations in a Combustion Field. Gerald Rosen. *ARS J.*, Apr., 1960, pp. 422, 423. ONR-sponsored study of the unsteady combustion of liquid propellant droplets entrained in a burned gas flow, in terms of an idealized mathematical model. The model is used to derive an associated equation for nonlinear pressure oscillations.

Procedimento di Calcolo dell'Impulso e della Frequenza Ottenibili con la Combustione Pulsatoria in Tubi. Dino Dini. *U. Pisa Fac. Eng. Paper 836*, 1958. 9 pp. Reprint. In Italian. Development of an approximate method for calculating the thrust and frequency of the pulsating combustion cycle in tubes. Numerical results show good agreement with experiment.

Issledovanie Fakela Goreniia Gomogennoi Benzovozdushnoi Smesi v Turbulentnom Potoke. N. V. Kokushkin. *AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom.*, Sept.-Oct., 1959, pp. 177–182. In Russian. Study of the combustion of homogeneous fuel-air mixtures in turbulent flow, and presentation of a method to measure the statistical characteristics of the shape of curved flame front surfaces and to determine the speed of propagation of this surface in relation to the mixture.

O Vozmozhnom Mekhanisme Usileniia Slabykh Udarnykh Voln v Zone Turbulentnogo Goreniia (K Teorii Vysokochastotnykh Kolebanii Plameni). K. I. Shchelkin. *AN SSSR Otd. Tekh. Nauk Izv. Energ. i Avtom.*, Sept.-Oct., 1959, pp. 86–96. In Russian. Study covering the mechanism of amplification of weak shock waves in the turbulent combustion zone observed in rocket power plants.

Heat Transfer

Heat Transfer. E. R. G. Eckert, J. P. Hartnett, T. F. Irvine, Jr., and E. M. Sparrow. *Ind. & Eng. Chem.*, Apr., 1960, pp. 327–339. 311 refs. Survey of investigations done in the fields of conduction, channel and boundary-layer flow, flow with separated regions, transfer mechanisms, natural convection, convection from rotating surfaces, combined heat and mass transfer, change of phase, radiation, liquid metals, low density heat transfer, measurement techniques, and heat-transfer applications.

Heat Transfer in Laminar Flow Between Parallel Plates at Small Péclet Numbers. H. C. Agrawal. *Appl. Sci. Res., Sect. A*, No. 2–3, 1960, pp. 177–189. Analysis of the effect of heat diffusion on the incident fluid for parabolic velocity distributions at small Péclet numbers.

Forced Convection Heat Transfer to Gaseous Hydrogen at High Heat Flux and High Pressure in a Smooth, Round, Electrically Heated Tube. J. R. McCarthy and H. Wolf. *ARS J.*, Apr., 1960, pp. 423–425.

Convection in a Fluid at Supercritical Pressures. J. D. Griffith and R. H. Sabersky. *ARS J.*, Mar., 1960, pp. 289–291. Description of investigations made to observe visually the fluid motion in the neighborhood of the heating surface, to determine if any bubble-like motion is present, and to relate this motion to any sharp increases in the heat transfer rate.

Measurements of the Heat Transfer Coefficient for Hydrogen Flowing in a Heated Tube. J. M. Fowler and C. F. Warner. *ARS J.*, Mar., 1960, pp. 266, 267. ONR-sponsored study.

Steady Temperature Field in a Semi-Infinite Composite Plate. Václav Vodička. *Appl. Sci. Res., Sect. A*, No. 2–3, 1960, pp. 190–196.

Heat Transfer by Laminar Flow from a Rotating Sphere. S. N. Singh. *Appl. Sci. Res., Sect. A*, No. 2–3, 1960, pp. 197–205. Analysis of heat transfer associated with the velocity field found by Nigam when the rotating sphere is maintained at a uniform temperature all the time. The fluid is supposed to be viscous and heat-conducting, and the velocity and temperature fields are assumed to be steady.

On the Effects of Sound Waves on Heat Transfer. J. P. Holman. *ASA J.*, Mar., 1960, p. 407. Discussion of the physical mechanism, as proposed by Westervelt, whereby heat transfer rates may be increased in the presence of intense sound fields.

Experimental Results of a Heat-Transfer Study from a Full-Scale Pebble-Bed Heater. R. B. Lancashire, E. A. Lezberg, and J. F. Morris. *U.S., NASA TN D-265*, Mar., 1960. 22 pp. 13 refs. Presentation of data obtained from the initial operation of a large regenerative pebble-bed heat exchanger. The facility, designed to produce high-temperature air for hypersonic flight research, is described in detail. The heat-transfer analysis and results are presented and compared with those of other investigators.

Laminar Heat Transfer Between Parallel Plates with an Unsymmetrically Prescribed Heat Flux at the Walls. R. D. Cess and E. C. Shaffer. *Appl. Sci. Res., Sect. A*, No. 1, 1959, pp. 64–70. Presentation of the first four odd eigenvalues and constants, as well as asymptotic expressions for these quantities, for laminar heat transfer.

VTOL & STOL

Towards Still Shorter Takeoffs and Landings. D. H. Henshaw. *Can. Aero. J.*, Apr., 1960, pp. 119–122. Review of a four-year STOL research program, covering such aspects as aerodynamics, performance and stability, and flight testing. A modified version of the Otter aircraft was used as the most suitable test vehicle for studying the dynamic problems associated with STOL flight.

The Cost of VTOL. K. B. Gillmore. (*IAS 28th Annual Meeting, New York, Jan. 25–27, 1960, Paper 60-43.*) *AHS J.*, Apr., 1960, pp. 13–19. Review of the differences between fixed-wing and tilt-wing aircraft as they affect empty weight. The analysis yields charts which indicate the conditions under which fixed- and tilt-wing aircraft will have equal empty weight and performance.

Helicopter and VTOL Aircraft: Criteria for Control and Response Characteristics in Hovering and Low-Speed Flight. R. J. Tapscott. *Aero/Space Engrg.*, June, 1960, pp. 38–41. Application of previously derived results, including those obtained on a conventional single-rotor helicopter (Sikorsky S-51) for control power and damping, as criteria for handling qualities in hovering and low-speed flight.

Endurance and Range of Jet-Supported and Jet-Propelled VTOL Aircraft. G. J. Sissingh. *AHS J.*, Apr., 1960, pp. 31–35. Development of charts that can be applied to any mission consisting of an arbitrary number and sequence of hovering and forward flight conditions, including the transfer of loads. It is assumed that within each individual segment of flight, the specific fuel consumption remains constant, but may change from one segment of flight to another.

6 Ways to Lift an Air Cushion Vehicle. *SAE J.*, Mar., 1960, pp. 26–29. Abridged. Discussion of the techniques of keeping a positive air pressure under the recently developed vehicles which move by sliding over a cushion of air. Three of the techniques aim to produce an air seal at the edge of the vehicle, two allow a limited leakage, and one uses the forward motion of the vehicle to ram air under it.

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REVIEWS OF *Books*

. . . in the field of aeronautical engineering and space technology

CATALOGS

Aero/Space Engineering Catalog, 1960. Beverly Dodge, Editor. 16th Ed. New York, Institute of the Aeronautical Sciences, Inc., 1960. 290 pp. $7.50.

This directory of products and their manufacturers is published annually by the IAS to serve the aerospace requirements of engineering and procurement departments in their consideration and selection of suppliers and subcontractors for their products. In the Principal Manufacturers section, the addresses and general product résumés of some 2,900 companies are included. The Products Directory contains well over 40,000 entries arranged under some 2,200 product headings; it is cross-indexed to assist the user. In addition, the directory contains an Index to Catalogs giving an alphabetical listing of firms whose catalogs, ranging from single-page units to multiple-page inserts, appear in the Manufacturers' Catalogs section of this edition.

DICTIONARIES

Elsevier's Telecommunication Dictionary in Six Languages: English/American, French, Spanish, Italian, German, and Dutch. Compiled by A. Visser. Amsterdam, Elsevier Publishing Co.; Princeton, N.J., D. Van Nostrand Co., Inc., 1960. 1011 pp. $27.50.

The first edition of this dictionary was published in 1955 by the Netherlands General Post Office for its own staff. The 9,928 entries are arranged alphabetically on an English alphabetical base. The equivalents in French, Spanish, Italian, German, and Dutch are then given. Following this basic table are alphabetical lists for each language, each word being numerically keyed to the basic table.

ELECTRONICS

The Technology of Printed Circuits; The Foil Technique in Electronic Production. Paul Eisler. New York, Academic Press, Inc., 1959. 405 pp. $12.

Contents: (1) The Basic Story of Printed Circuits. (2) The Confused Start of a New Technology. (3) The Principles of Method Selection and the Foil Technique. (4) Watching Printed Circuit Production. (5) From the Drawing to the Photo-Stencil. (6) Litho Printing. (7) Photomechanical Printing Processes. (8) Plating and the Foil Technique. (9) Ancillary Operations. (10) Laboratory Routine. (11) Design. (12) Conventional Components for Assembly with Printed Circuits. (13) Printed Circuit Trouble Shooting. (14) Automatic Assembly in the Electronics Industry. (15) Regeneration of Ferric Chloride. (16) Weight Saving and Heat Dissipation. (17) Miniaturization. (18) Printed Components. (19) Microwave Printed Circuits: A Short Survey. (20) Printed Circuits and the Electronics Industry. Appendix 1: Examples of Commercially Available Adhesives for Foil Bonding. Appendix 2: The Control of Strength of Etching Solutions. Appendix 3: Double Layer Process. Appendix 4: Plating Solutions and Some Principles of the Automatic Plating Plant. Appendix 5: Description of R.C.A. Programmed Punching Machine. Appendix 6: Approximate Analysis of the Characteristic Impedance of Flat-Strip Transmission Lines. Appendix 7: Characteristics of Flat-Strip Transmission Lines of Importance in Applications. Bibliography of Printed Circuits (481 references, annotated). Author Index. Subject Index.

Electronic Circuits, Signals, and Systems. Samuel J. Mason and Henry J. Zimmerman. New York, John Wiley & Sons, Inc., 1960. 616 pp. $12.50.

This is the companion volume to *Electronic Circuit Theory*, by Zimmerman and Mason, published in 1959. It presents methods suitable for handling more general circuits, with more general signals applied. These methods form an introduction to system theory. More specifically, Chapters 2–5 are concerned with matrix, topological, and signal-flow-graph methods of circuit analysis. Chapter 6 introduces Fourier theory and applies it to the description of signals, including some random signals. Chapter 7 uses amplifier circuits to illustrate the transmission of signals through linear systems, with transform techniques and convolution providing the basic mathematical tools. Chapter 8 applies the foregoing material to nonlinear and time-varying linear systems. Chapter 9 brings both the analytical and the topological methods to bear upon simple systems that exploit the negative-feedback concept.

The authors are Professors of Engineering, M.I.T., and staff members of the Research Lab. of Electronics.

Quantum Electronics; A Symposium. Edited by Charles H. Townes. New York, Columbia University Press, 1960. 606 pp. $15.

This volume contains the 67 papers and the discussions presented at the ONR-sponsored Conference on Quantum Electronics—Resonance Phenomena held at Shawanga Lodge, High View, N.Y., on September 14–16, 1959. Recent developments in masers, atomic clocks, paramagnetic resonance, optical pumping, parametric amplifiers, the application of very sensitive amplifiers to radio astronomy, and quantum effects in amplifiers and communications are presented to give a comprehensive view of current research.

FLUID MECHANICS

The Scientific Papers of Sir Geoffrey Ingram Taylor; Vol. 2, Meteorology, Oceanography, and Turbulent Flow. Edited by G. K. Batchelor. Cambridge, at the University Press; New York, Cambridge University Press, 1960. 515 pp. $14.50.

This second volume is the first of three to be devoted mostly to work on the mechanics of fluids and contains 45 papers that have appeared in many scientific journals and reports published in Great Britain, France, Germany, and the United States. The phenomenon of turbulence and its effects provide the main theme of this volume, but it also contains a wide range of geophysical investigations. Diffusion in the atmosphere, formation of fog, tidal friction, tidal oscillations in gulfs, oscillations of the atmosphere, stability of stratified fluids, and convection from maintained and instantaneous sources have all engaged Taylor's attention at some time, and to each of these problems he has made a contribution. Some of the early papers on meteorology show clearly how he evolved the ideas that led to his well-known work in the 1930's on the statistical theory of turbulence.

LAWS & REGULATIONS

Aircraft Mortgage in the Americas; A Study in Comparative Aviation Law, with Documents. S. A. Bayitch. (University of Miami School of Law Interamerican Legal Studies, No. 5, 1960.) Coral Gables, Fla., University of Miami Press, 1960. 159 pp. $4.75.

MATHEMATICS

Operational Calculus. Jan Mikusiński. Warsaw, Państowe Wydawnictwo Naukowe; New York, Pergamon Press, Inc., 1959. 496 pp. $15.

To date there have been four editions of this book: the first in Polish (Warsaw, 1953), the second in Russian (Moscow, 1954), the third in German (Berlin, 1957), and the fourth in Polish (Warsaw, 1957). This first English edition was translated from the second Polish edition and has been enlarged, primarily by the addition of an appendix of 112 pages containing (1) the proofs of theorems omitted in the earlier editions, (2) new results in operational calculus obtained since the publication of the first edition, (3) a discussion of the relations between operational calculus and other branches of mathematics, and (4) problems as yet unsolved.

In this book operators are introduced algebraically as kinds of fractions. They are a generalization of the concept of numbers; operations on them are performed in the same way as operations on numbers. This treatment is simpler and more general than those based upon the Laplace transform and can be understood by readers who are not acquainted with the theory of analytic functions. The author, a professor at the University of Warsaw, has prepared the book with the needs of both the engineer and the mathematician in mind.

NUCLEAR ENERGY

Soviet Nuclear Propulsion (Iadernye Dvigateli). R. G. Perel'man. (Moscow, Izd-vo "Znanie," 1958.) Washington, Triumph Publishing Co., 1960. 46 pp. $2.85.

Among the topics discussed in this booklet for the general reader are nuclear engines, ships, and submarines, nuclear rail and land transportation, and aircraft and rocket nuclear propulsion.

Nuclear Power Plant. E. Openshaw Taylor. New York, Philosophical Library, Inc., 1960. 184 pp. $7.50.

This book opens with an account of world energy requirements and resources. It goes on to deal with nuclear and reactor physics, types of reactors, reactor engineering, instrumentation and control, and the economics of nuclear stations. The appendixes contain tables of elements, information on the mean free path of neutron travel and on reactor theory, and a chronology of nuclear power.

Nuclear Fusion. Edited by William P. Allis. (The Second Geneva Series on the Peaceful Uses of Atomic Energy.) New York, D. Van Nostrand Co., Inc., 1960. 488 pp. $12.50.

This volume contains the most significant ideas on fusion as presented at the 1958 conference in Geneva by contributors from eleven nations, including the U.S.S.R., Poland, and Rumania. The first chapter contains survey papers on controlled thermonuclear research carried out in the United States, Great Britain, and the Soviet Union; the next four discuss general plasma properties, including diagnostics, waves, equilibrium, and stability and dynamics. The final six chapters describe the several types of thermonuclear machines currently in service: stellarators, pyrotrons, ring discharge devices, injection machines, and sustained and dynamic pinches. The concluding appendix contains a listing of all the papers presented at the Second Geneva Conference. References are given at the end of each chapter. The editor is with the Physics Dept., M.I.T.

RESEARCH

Science and Engineering in American Industry; Report on a 1956 Survey. Prepared for the National Science Foundation by the U.S. Department of Labor, Bureau of Labor Statistics. (NSF 59-50.) Washington, Supt. of Docs., 1959. 116 pp. $0.70.

This report presents the results of a comprehensive survey of funds and personnel for industrial research and development.

SPACE TRAVEL

Proceedings of the Manned Space Stations Symposium, Los Angeles, Calif., April 20–22, 1960. Sponsored by the Institute of the Aeronautical Sciences with the cooperation of NASA and The RAND Corporation. New York, IAS, 1960. 322 pp. $10 (IAS Members, $5.00).

Contents: Manned Space Flight—Present and Future Steps, Robert R. Gilruth and H. Kurt Strass. The Military Test Space Station, Lowell B. Smith. Atmospheric Entry of Manned Vehicles, C. Gazley, Jr. Design Criteria and Their Application to Economical Manned Satellites, H. H. Koelle, E. E. Engler, and J. W. Massey. A Modular Concept for a Multi-Manned Space Station, S. B. Kramer nd R. A. Byers. Manned Scientific Orbital Laboratory, M. Stoiko, G. G. Kayten, and J. W. Dorsey. Some Factors Influencing the Selection of a Manned Space Station Concept, J. H. Doss and L. J. Montague. Crew Requirements for an Orbiting Space Station, R. H. Lowry. Work and Living Requirements for Manned Space Stations, F. A. Payne. Gravity Problems in Manned Space Stations, C. C. Clark and J. D. Hardy. Man's Contribution to an Operational Space Station Concept, M. A. Grodsky and R. D. Sorkin. Program Costs for a Manned Space Station, R. H. Lundberg and T. E. Dolan. Satellite Astronomical Observatories, Nancy G. Roman. Structural Implications of the Ionizing Radiation in Space, Norris F. Dow. Design of an Operational Ecological System, E. B. Konecci and N. E. Wood. Orbital Rendezvous and Guidance, Ernest A. Steinhoff. Rendezvous in Space—Effects of Launch Conditions, N. V. Petersen and R. S. Swanson. Ascent Guidance for a Satellite Rendezvous, T. B. Garber. A Guidance Technique for Achieving Rendezvous, P. G. Felleman and N. E. Sears, Jr. Manned Control of Orbital Rendezvous, E. Levin and J. Ward. Inflatable Manned Orbital Vehicles, J. W. Carter and B. L. Bogema. The Role of Damping in Space Structures, C. W. Coale. A Structural Approach to the Thermal Control of Space Vehicles, Peter E. Glaser. A Comparison of Nuclear and Solar Power Systems for Manned Space Stations, W. C. Cooley. Integrated Thermodynamic Systems for Manned Space Stations, M. G. Del Duca, A. D. Babinsky, and F. D. Miraldi. Utilization of Plasma Cell Energy Conversion in Nuclear Reactors, W. A. Ranken and T. G. Frank. A Circulating Dust-Fueled, Radiation-Cooled Space Power Reactor, W. R. Corliss. The Use of Chemical Power Systems in the Construction, Servicing, and Operation of Manned Space Stations, H. J. Howard and R. M. Laughlin. Methods of Attitude Sensing, Robert E. Roberson. Comparison of Some Actuation Methods for Attitude Control of Space Vehicles, W. Haeussermann. Attitude Control of a Space Vehicle by a Gyroscopic Reference Unit, M. L. Chatkoff and L. G. Lynch. Attitude and

Flight Path Control for a Space Station Supply Vehicle, J. Stalony-Dobrzanksi and O. Imai. Gaseous Environment and Ecological Systems, C. J. Lambertsen.

Artificial Earth Satellites; Vols. 1 and 2. Edited by L. V. Kurnosova. Translated from Russian. (Iskusstvennye Sputniki Zemli; Moscow, Izdatel'stvo Akademii Nauk S.S.S.R., 1958.) New York, Plenum Press, Inc., 1960. 107 pp. $9.50.

Volume 1 of this work explores the data obtained by the first two Soviet satellites to orbit the Earth during the period from Oct. 4, 1957 to April 14, 1958. Data collected on the dog Laika are also presented. Volume 2 contains the results of scientific investigation carried out with the third satellite, as well as work with rockets. These articles are the revised texts of the reports presented at the Fifth Assembly of the Special IGY Committee, Moscow, Aug., 1958.

The Other Side of the Moon. Translated from the Russian by J. B. Sykes. Issued by the U.S.S.R. Academy of Sciences. London, New York, Pergamon Press, Inc., 1960. 36 pp. $2.50.

The results of a preliminary study of the photographs made from the lunar probe launched in the Soviet Union on Oct. 4, 1959. This book contains reproductions of photographs and information on the design of the automatic interplanetary station, its orbit around the Earth and the Moon, the photograph and image transmission employed, and the features noted in the photographs.

STRUCTURES

Fundamentals of Stress Analysis. Albert Deyarmond and Albert Arslan. 2nd Ed. Los Angeles, Aero Publishers, Inc., 1960. 256 pp. $5.75.

This edition covers the basic concepts of structural analysis, with an introduction to the basic theories of different types of beams, trusses, and columns. It contains numerous practical examples as they apply directly to wings, fuselages, and missile shell analysis. An extensive appendix contains formulas, tables, and other data pertaining to structural shapes and materials.

THERMODYNAMICS

Flames; Their Structure, Radiation and Temperature. A. G. Gaydon and H. G. Wolfhard. 2nd Rev. Ed. New York, The Macmillan Co., 1960. 383 pp. $14.

As in the first edition which appeared in 1953, the aim of the present volume is to give a fairly advanced discussion of a part of combustion that is concerned with stationary flames, with the emphasis on the physical rather than the chemical viewpoint. Chapter 14 is now chiefly concerned with rocket-type fuels (e.g., boron, fluorine and nitrogen compounds). Chapter 15, devoted to recent progress on flame problems, has also been completely rewritten. References to over 200 new papers have been added. Dr. Gaydon is with the Chemical Engineering Dept., Imperial College, London; Dr. Wolfhard is Manager, Physics Dept., Reaction Motors Div., Thiokol Chemical Corp.

VIBRATION

Theory of Mechanical Vibration. Kin N. Tong. New York, John Wiley & Sons, Inc., 1960. 348 pp. $9.75.

This book is the outgrowth of lecture notes for a course given to beginning graduate students and qualified seniors and is primarily a textbook, although some utility as a reference volume is also intended.

Chapter 1 treats systems having a single degree of freedom. All the basic concepts pertaining to mechanical vibrations are presented, with the exception of vibration modes. Chapter 2 introduces the concept of vibration modes in a multidegree-freedom system, using a system with two degrees of freedom as a simple model. By means of matrix algebra and generalized coordinates, Chapter 3 extends the results previously obtained. In this way this chapter also lays the foundation for the solution of vibration problems on digital computers and provides an heuristic picture of what is to follow. Chapter 4, the final chapter, discusses the vibration of continuous media. The book closes with an outline of matrix algebra employed in the linear transformation of vectors.

The author is Professor of Mechanical Engineering, Syracuse University.

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electrical or mechanical engineers

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